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A

TREATISE

ON THE

STEAM-ENGINE.

FROM THE SEVENTH EDITION

OF THE

ENCYCLOPÆDIA BRITANNICA.

BY

JOHN SCOTT RUSSELL, M.A. F.R.S.E.

VICE-PRESIDENT OF THE SOCIETY OF ARTS

FOR SCOTLAND, &c., &c., &c.

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PREFACE.

The articles Steam and Steam-Engine in the former edition of the Encyclopædia Britannica were written by Dr Robison. The college companion of James Watt became the historian of his achievements, the expounder of inventions of which he had closely watched the origin and progress. His articles are distinguished by that clearness of conception, closeness of reasoning, and gracefulness of style, which entitle him to be ranked among the soundest and most accomplished of those authors who have contributed to the advancement of mechanical science. These articles have long formed the standards of our knowledge, and are still the fountain-head to which we resort for information. To Sir David Brewster we are indebted for the publication of certain contributions to these original articles which have enhanced their value: to his edition of Dr Robison's works, Mr Watt himself undertook to contribute notes and additional matter, and thus became at once the historian of his own inventions and the commentator on the writings of his early friend.

Thus, the friendship of these two distinguished

individuals, commencing with the warmth of youthful companionship, continuing through the vicissitudes of lives longer than the usual term of humanity, and descending into their graves—is embalmed in these their joint contributions. It appeared to the writer of these pages, that he could not better discharge the duty devolved upon him, in accepting the responsibility of the articles Steam and Steam-Engine, in the seventh edition of the Encyclopædia Britannica, than by retaining as much of those original contributions of Robison and Watt as could consist with the present advanced state of knowledge and practical art. Considerable portions of them are, therefore, presented to the reader exactly as they came from the pens of Robison* and Watt,† distinguished by their names or the accompanying marks; and to these valuable gems his own contributions serve only as the mere "setting" required to connect them with the now extensive structure of practical science.

In the joint lives and labours of Robison and Watt, we open one of the brightest pages of the "friendships of philosophy"—intellectual prowess was in them remarkably conjoined with the virtues and amiabilities of social life, and it is difficult to say, whether we more admire the philosopher, or love the man. Akin to these feelings appear to have been the sentiments with which through a long life they regarded each other. Fortunately, the records of these sentiments

still exist in notices written by themselves. Robison's sketch of Watt is already before the public; but we have now the pleasure of presenting to our readers, a companion sketch of Robison drawn by Watt himself, which we owe to the kindness of Sir John Robison, and which in April 1805, was addressed by Watt to the widow of the departed friend of his youth.

Mr Watt's sketch of Dr Robison.

"Our acquaintance began in 1756-7, (Mr Robison being then 17,) when I was employed by the University of Glasgow to repair and put in order some astronomical instruments, bequeathed to the University by Dr Macfarlane of Jamaica—Mr Robison was then a very handsome young man, and rather younger than me. He introduced himself to me, and I was happy to find in him a person who was so much better informed on mathematical and philosophical subjects than I was, and who, while he was extremely communicative, possessed a very clear method of explaining his ideas. Between two young men of ardent minds engaged in similar pursuits, a friendship was soon formed, which has continued until death has deprived me of my friend, and has suffered no other interruption than what has been caused by our absence from each other, and the necessary attention to our respective duties in life.

Soon after this, I settled as mathematical instrument maker in the college of Glasgow, and was favoured with Mr Robison's company until he left the college about the end of 1758 and went to sea—I believe in one of his Majesty's ships.

"During this period, he turned my attention to the steam engine, a machine of which I was very ignorant, and suggested that it might be applied to giving motion to wheel carriages, and that for that purpose it would be most convenient to place the cylinder with its open end downwards, to avoid the necessity of using a working beam. The latter idea he had published some time before in the *Universal Magazine*.—In consequence, I began a model with two cylinders, of tin plate, to act alternately by means of a * * * acting on two pinions attached to the axes of the wheels of the carriage; but the model being slightly and inaccurately made, did not answer expectation. New difficulties presented themselves; both Mr Robison and myself had other avocations requiring our attention, and neither of us having then any idea of the true principles of the machine, the scheme was dropped. I however went on with some detached experiments on steam, until 1763, when I set about the matter more seriously, and discovered the principles upon which my improvements on the steam engine were founded."

Beside this we place the following extract from the Eloge of Watt; being—

Dr Robison's Sketch of Young Watt in His Workshop.

"When I was as yet a young student, I had the vanity to think myself a pretty good proficient in my favourite studies of mathematical and mechanical philosophy, and on being introduced to Watt, was rather mortified at finding him so much my superior. Whenever any of us stumbled on a difficulty, we went to Watt; he needed but to be prompted; every thing became to him the beginning of a new and serious study, and we knew that he would not quit it till he had either discovered its insignificancy or made something of it. . . . On one occasion, the solution of a problem seemed to require the perusal of Leupold's Theatrum Machinarum—and Watt forthwith learned German; at another time, and for a similar reason, he made himself master of Italian. . . . when, to the superiority of knowledge which every man confessed, is added the *naive* simplicity and candour of Mr Watt's character, it is no wonder that the attachment of his acquaintance was strong. I have seen something of the world, and am obliged to say, I never saw another such instance of general and cordial attachment to a person whom all acknowledged to be their superior. But this superiority was veiled under the most amiable candour and liberal allowance of merit to every man—Mr Watt was the first to ascribe to the ingenuity of a friend, things which

were very often nothing but his own surmises, followed out and embodied by another. I am well entitled to say this; having often experienced it in my own case."

Below this sketch Mr Arago has written a note, to which we shall every one subscribe:—"It is difficult to determine whether the honour of having uttered these last words is not as great as that of having inspired them"—and, with both sketches before us, we are equally left in doubt whether each were not fully entitled to all the encomiums his friendship has passed on the companion of his youth and the unchanged friend of declining age.

In the present articles, it has been the author's aim to add to all that Robison had originally said of Watt's invention, what he would have required to add if he had lived to witness its present extended use, its multifarious applications, its varied forms, its modifications in materials and construction. In all else—in principles, in useful effect—little has been added, though much has been changed since the machine came out of the hands of the original inventor. The author has to regret the inadequacy of his work to the design which he had formed, and its defects, even when compared with his own standard of excellence. Unfortunately the duties of a laborious profession allow him little leisure for literary exertions. He has however endeavoured to place before the reader, in a simple form, all the most important information which many years of research and of practical experience in

a favourite subject, have placed in his possession; and the reader who is familiar with the subject will readily discover that he has read and thought for himself, and that his errors, if many, are at least his own. In one point he trusts he has facilitated the progress of the student. While giving the general reasoning of complex calculations, he has endeavoured to disembarrass them as much as possible of that parade of calculus which exhibits the author at the expense of the reader; and rather to present their results in that simple form in which alone great truths present themselves to those who thoroughly understand them. In treating an extensive subject in a limited space, he has also preferred to present general truths, rather than to enlarge upon minute details and multifarious definitions, which often lead the reader to imagine he understands a subject when he only remembers the technical phrases in which it is conveyed, having acquired nothing more than that species of mere word-knowledge deplored by Bacon—

"Qui voces artis habeant in promptu, etiam artes ipsas perdidicisse existimentur."

It is further necessary, that the intelligent reader who shall happen to compare these articles with any other treatises that may have recently appeared, should be apprized that a great part of them was written a considerable time ago, and that the commencement was actually in the press two years before

the present date of publication; its alphabetical place in the Encyclopædia, and other impediments, having delayed its appearance till now.

The author would be unjust to the editors of the Encyclopædia Britannica did he not acknowledge the benefit this article has derived from their supervision. The multifarious duties of his profession, and prolonged absence from home and on the Continent, have in a great measure precluded his own supervision of the press. To them belong at once the merit and the responsibilities of the active editorship of these articles.

The application of the steam-engine to locomotive purposes has already been treated in the article "Railways" in the former volume of the Encyclopædia.

The literature, as well as the science, of steam navigation is still very imperfect; and this article can only be considered as contributing some materials towards a treatise on that subject. Imperfect though it be, it contains the results of many years of laborious research and personal examination and experience. The historical statements are made on the highest authority, the oral or written testimony of eye-witnesses of the facts communicated to the author. The generalized facts of the latter part represent the qualities and performance of the *chef d'œuvres* of the best constructors, in most cases ascertained personally by the writer in his own experience, or directly communicated. Where he has committed errors or omissions

he will gratefully receive correction—especially from any kind readers who may happen to be acquainted with the merits of any one who has contributed to the advancement of steam navigation, and of whose achievements the author has the misfortune to be ignorant.

Many of the valuable drawings from which the plates were engraved, have been contributed with great kindness by the engineers whose work they are, and whose names they honour.

The reader who consults an article of an Encyclopædia, will not expect to find every thing said concerning every one of the subjects that are within its title. The following memorandum may be of service to the reader whom these pages may inspire with the wish to know more of the subject.

Mr Farey's large quarto volume on the steam-engine, is the most satisfactory work ever published on those departments of the subject which it comprehends; but unfortunately the work is still incomplete.

Mr Stuart's historical writings on the steam-engine are well worthy of perusal. His research has been unwearied, and, although microscopic critics have detected minute errors, he is in general most trustworthy.

M. De Pampbour's treatise, and Mr Robert Stephenson's, contain clear descriptions and excellent experiments on the application of the steam-engine to railway transit.

Mr GORDON's "Treatise on Elemental Locomotion," gives an interesting account of almost all that has been done for the introduction of carriages propelled by steam on common roads.

"TREDGOLD's Treatise on the Steam-Engine," contains several interesting tracts and many valuable plates.

Besides these, the engineer's library on steam now contains above a hundred volumes, for the titles of which he may consult bibliographical works. He will find interesting discussions, valuable facts and ingenious devices in steam spread through the journals of the last thirty years—especially in the transactions of the Royal Societies, the Philosophical Magazines, the Mechanics' Magazine, the Patent Registers, and Nautical, Railway, and Engineers' Journals;—from all of which the author has obtained much valuable information.

VIRGINIA HOUSE, GREENOCK, 23*d April*, 1841.

THE STEAM-ENGINE.

It is a singular peculiarity in the history of the steam-engine, that, ever since the period which exhibits the earliest traces of its embryo, it has continued slowly and gradually to advance with the flow of time towards its present state of high maturity, though not yet, perhaps, of ultimate perfection. Other arts and inventions, once well known and successfully used, after having attained a certain measure of perfection, have again been lost sight of amid the ruins of empires and the revolutions of nations, never more to be rescued from oblivion. While some of these, on the one hand, have sprung suddenly up into maturity, arrayed in the panoply of immediate power, being sent as it were directly by divine mission, to perform some important part in the destinies of the world, perfect from their birth, there exists another class of inventions and of sciences that have themselves undergone so many revolutions as, in the later part of their history, to present nothing more than the name in common with the maturer knowledge of the

present day. But our knowledge of the properties and powers of steam, and its agency by a steam-engine, differs in every way from the progression of other arts and other knowledge. Known in the earlier ages of Egyptian science, it appears to have played its part in adding to the imposing effect of those stupendous monuments of absolute power which the storms of thousands of years have failed to obliterate. In the more refined ages of Greece, steam appears to have ministered alternately to the elegance of Attic luxury and the delusions of heathen idolatry; and to have become extensively known until the destruction of the Alexandrian schools of science dispersed those seeds of mechanical science which the flames of its library have spared to Western Europe; and there, imbedded in the ruins of learning during the dark ages of second barbarism, they lay preserved, but unfructifying, among the other remains of the learning of the middle ages; and when at length the light of knowledge once more dawned on Europe, the science of the Greek philosophers was exhumed from the rubbish which had concealed it, and revealed to the dawning light by the mighty lever of the press. The work of Hero on *Pneumatics and Steam Machinery* was one of the finest and earliest specimens of the art of printing. Since that time the science of steam, and the art of constructing the steam-engine, have made slow, regular, and progressive advancement, until this mighty work of many hands has at last attained a prominent importance in the interests of humanity, and become a mighty element in the future destinies of the world. In this remarkable course there has been no retrogradation. Centuries have added their contributions to the elucidation of its principles and

the perfection of its mechanism; but no great revolution has ever thrown back, nor any single effort reproduced the mighty machine.

It is this peculiarity which has induced us to present to our readers the history of the steam-engine as the most apt and useful introduction to the perfect comprehension of its principles and structure. In many other subjects the history of the science or art is little more than an interesting and curious antiquarian research, fascinating to the virtuoso, and even instructive to the historian or philosopher, but by no means necessary, or even conducive, in any degree, to the acquisition or comprehension of the modern condition of our knowledge. What, for instance, have the astronomical systems of the Chaldees or the Greeks to do with the Copernican system of modern astronomy? In what degree would a learner be assisted in comprehending the sublime doctrines of the celestial mechanics of Newton, by having made himself thoroughly acquainted with the cycles of Hipparchus and Ptolemy, the crystal spheres of Frascatorius, or the multitudinous epicycles of Purbach? But with our knowledge of the phenomena and the powers of steam, the case has been widely different. The progress of the steam-engine has been co-ordinate with the progress of the human mind in physical truth. The history of the past improvements of the steam-engine is therefore the history of the human mind; and the same phases which have been severally presented, at widely separated epochs, by successive inventors, are the very phases of gradually growing knowledge by which a single individual mind does most naturally and most profitably proceed, step by step, to the full blaze of light which is thrown upon this subject by

the illumination of modern science. Of so large a subject, one part only can be studied at a time, and that succession of parts by which they enter into the mind in easiest transition is the very succession in which history presents them to us.

We shall therefore divide this subject into two parts: the first containing a description of the steam-engine, and the elucidation of its principles, in historical order; the second forming a description of the functions and parts of the modern steam-engine.

PART I.—HISTORICAL DESCRIPTION OF THE STEAM-ENGINE. 1. THE ERA OF THE ANCIENTS. 2. THE ERA OF WORCESTER. 3. THE ERA OF WATT.

1. *The Era of the Ancients.*

The knowledge which some of the ancients possessed of the constitution of steam is remarkably in accordance with the most recent modern conclusions on this species of matter. Steam is now known to be only one of the common airs or gases whose particles at one degree of heat and of pressure assume a liquid form, and at another temperature and pressure become solid ice.

The modern doctrine concerning matter may be thus stated; that matter is known to exist in four conditions—solid, liquid, aerial, and etherial. Earth and stone are exemplars of solid matter; water and mercury of liquid matter; the atmosphere, and smoke, and steam, of aerial substances; caloric, light, and electricity, of etherial matter. It is further the doctrine of modern physics that no kind of matter exclusively possesses one of these conditions as its distinguishing property, but that all may, in

certain circumstances, assume different conditions. Stone is not essentially solid, for, by the action of heat, it may be melted under pressure; and iron or lead, though usually solid, may be presented in the liquid form; and the earths have likewise assumed the form of liquids when the contrivance of the chemist has succeeded in placing them in appropriate circumstances. Neither is water essentially a liquid, for, when frozen, it becomes a solid, with which we may construct houses, bridges, utensils, and even floating structures capable of navigating the ocean; and, on the other hand, it is sometimes reduced into the vaporous or aerial form, as when the water of a vessel, acted on by heat, is wholly dissipated and dispersed in an invisible form in air.

It is also to be observed, that the condition of a body may be changed by the agency of heat. Solid ice, solid mercury, or solid lead, by the addition of heat, are converted into liquids, or are melted; and form liquid ice, (called water,) liquid mercury, (called quicksilver,) and liquid lead, (which has no separate name.) If to the liquid thus produced from the solid we add a certain other portion of heat, which will separate its particles still further from each other, the matter thus diffused over more extended space becomes reduced to the aerial condition of steam, of mercurial or lithargical gas, or transparent vapour. But still the matter has undergone no constitutional change. It is only necessary to remove the heat, and the particles will again come together and resume their primitive form. By cooling down the aerial gas into which the matters had been dissipated, or even by compressing them, so as to contract them into their original bulk and bring them together into their original prox-

imity, the particles will once more resume their pristine form, the vapour will respectively appear as drops of liquid water, mercury, or lead, and those liquids being more condensed, will congeal into the original solid masses of solid ice, solid mercury, and solid lead. The most refractory gases have actually been found to obey this law, and we have no doubt that every substance in nature might successively be presented to the senses in every one of these forms.

The following passages, taken from the *Timæus* of PLATO, present a remarkable accordance with these enlarged views of the constitution of steam and other gases:—" Let us therefore speculate concerning the nature and properties of fire and water, air and earth. This is the more arduous, because it is necessary to call into question, concerning each and all of them, whether they should be denominated liquid rather than etherial, or aerial rather than solid; or why any thing should have one of these appellations rather than all. For, in the first place, that which we now call 'water,' being congealed, becomes (hard) as a stone or earth, but being melted and diffused becomes gas or air, and this inflamed becomes fire, and fire extinct becomes again congregated into air, and air collected and condensed forms mist and cloud, and these again, more compressed, form water, and from the water earth and stone are reproduced. And thus they, in an endless circuit, produce each other. Since, then, these now appear to be the same, who will assert that one of them is of the one kind rather than the other? It is most safe, therefore, to speak thus: that the thing we see is not absolute liquid, but something in the liquid state. That air is not necessarily a gas, but some-

thing in the gaseous state; not as being a particular thing of this or that specific nature, but that it is in such and such a condition."

"Let us then distribute the four modifications of matter into fire, earth, water, and air; and to earth let us assign an entical form, for it is the most immovable of all these kinds—to water that which is less movable than the other three—to fire the most easily movable form—and to air that which is intermediate."

It appears to us highly probable that the ancients knew more of the phenomena of steam than has been generally admitted. One evident cause of this mistake is the circumstance that no specific term equivalent to the word steam was generally used by them; and water, when heated, was said to be converted into an air. It is now almost perfectly established by the progress of modern science, that steam is an air, (or gas,) invisible and perfectly transparent, differing in none of its mechanical properties from common air or gas, and in no respect differing in its constitution from carbonic and other gases or airs which, at certain temperatures and pressures, do, like steam, leave the elastic aerial form and become condensed. Many of the phenomena, therefore, for which the ancients use the word air, are effects of steam, or of steam mixed with air; and although they have not always carefully distinguished these separate effects, yet they have frequently made judicious use of them. While, therefore, it would be wrong to draw any parallel between the want of individualization manifested in their writings, and the high generalization of modern science, it would be equally wide of truth to deprive them as has sometimes been attempted, of the

merit of having discovered and used some of the properties of water in the aerial state, simply because they supposed it rarefied into an air, and confounded its phenomena with those of other gases, which, mixing with it, also contributed to the effect—as when we find that air rarefied by heat, and water rarefied into air, are mentioned.

HERO OF ALEXANDRIA, in his *Pneumatics*, has collected the science and inventions of the ancients, along with some of his own, into a systematic treatise, written in Greek, more than 120 years before the Christian era, some passages of which are identical with portions of modern treatises on pneumatics: and many portions of his apparatus may be found transformed into modern experimental models in cabinets of the physical schools. Now, in the introductory portion of his work, we have such statements as these:—*Water is transformed into air by the action of fire. For the vapours of boiling caldrons are nothing else than attenuated moisture expanding into air.* Indeed, by the four elements the ancients appear to have meant the same things which we now designate by different terms. We comprehend all the material agents with which we are acquainted under the four great designations, solids, liquids, air, and ether. So exactly had the ancients their πυρ and αηρ, ὑδωρ, and γη, to which they assigned different regions according to their weight; first, the solids or earth, then the liquids above, next the aerial covering, and finally the region of ether extending indefinitely beyond. The moderns have shown that all bodies are probably capable of assuming any of the three states, and becoming solid, liquid, or fluid, according to the circumstances in which

they are placed; and we have every reason to believe that Timæus, of whom Plato speaks with so much reverence, entertained the same idea, and believed that even the air might assume the state of a crystalline solid. It is not a little curious to find a mathematician of the present day giving it as a result of his calculus, that the air at a great distance from the earth is actually frozen into a crystalline solid by the extreme depression of temperature. He was probably not aware that his notion had been anticipated more than 2000 years. In this same work of Hero, we have descriptions and explanations of apparatus, in which the power of fire acting on moisture and air is made to produce phenomena of motion. He does not arrogate to himself the merit of these inventions, but has given them as principally a collection from the works of those ancients who had long preceded him—*the ancient philosophers and mechanics.*

His *Pneumatics* commence with a lucid and excellent dissertation on the properties of air as a medium for the communication of pressure and motion, and especially upon the nature and effects of a vacuum, subjects to be thoroughly understood by all who would master the theory of the steam-engine. It is, indeed, as the means of producing a vacuum, that steam obtains much of its value as a mechanical power. The mode of raising water by a vacuum is thus described by him:—"When they wish to fill with water the round medical glasses which have slender long necks, they suck out the air which is contained in them, and, closing the orifice with the finger, they invert them in the water, and on removing the finger the water is drawn up into the vacuous space, in contradiction to the usual law of fluids." He then pro-

ceeds to state that, "in like manner, air may be rarefied by heat even as other substances are; for water is changed by fire into air, the vapours from boiling caldrons being nothing else than expanded water taking the form of air, and that mists and clouds are nothing else than water raised in the air by heat, which are partly afterwards converted into air, while portions again descend in rain." He also attributes the origin of winds to the "expansion and contraction of air and moisture by the alternate heating and cooling produced by the sun's rays;" and illustrates the conversion of liquids into air or gas by the common observation, that, after a lamp has gone out, the vapour continues to rise up by the heat still left in it by the flame. Thus also, says he, a phial being filled with heated air and inserted in water, this air contracting will draw up water into the phial. Hence, he argues, that all airs consist of inconceivably small particles of matter, between which there are left wide vacuous spaces, so that, while the matter itself is incompressible, the volume occupied by the aggregate may be increased and diminished, and the air rarefied and condensed either by external force or the action of heat.

Fig. 1.

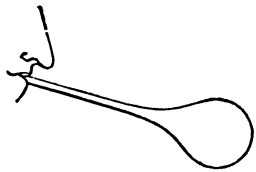


Fig. 2.

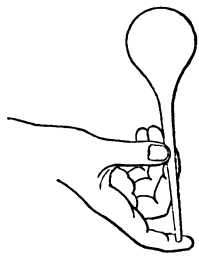
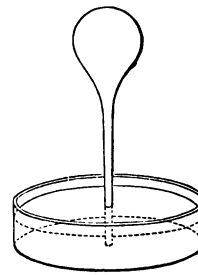


Fig. 3.

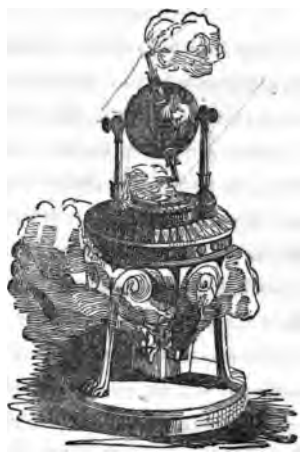


The following description of the manner in which the force of steam, issuing from a boiler, may be applied to supporting a weight, is given in the *Pneumatics*. "A boiler, perforated on the top, is placed on the fire. From the perforation there proceeds a tube, on whose extremity is fixed a hollow hemisphere perforated in like manner. If then we place a light ball in the hemispherical cup, it will follow that the vapour rising up from the boiler through the tube will support the sphere, and it will appear to dance."

Fig. 4.

There is another apparatus in the *Pneumatics* for the purpose of producing a revolving motion by the action of steam—"by a caldron placed on a fire to give motion to a sphere around its axis. Let a boiler be set on the fire, and nearly filled with water, and let its mouth be closed in by a cover, and let it be pierced with

Fig. 5.



an opening through the bent tube, whose extremity exactly fits into the hollow sphere. But at the opposite extremity of the diameter let there be an iron axis supported from the top of the cover; and let the sphere have two bent pipes at the ends of a diameter perforated along with it, and bent round in opposite directions; and let the bendings make right angles and be in the plane perpendicular to the axis. Then it will follow that, on the boiler being heated, the vapour rushing through the tubes into the sphere will rush out through the reversed pipes of the ball, and whirl it round on its axis."

The same apparatus, on similar principles, is next applied by Hero to the construction of a machine still more curious. The agent mentioned in this case is rarefied air, although the action is of precisely the same nature. Here the science of the philosopher appears to have been degraded to the base use of assisting an idolatrous priesthood in deceiving the populace by the resemblance of miraculous interference. "A fire having been kindled upon an altar, living figures will appear to lead a choral dance, even although the altar itself be of transparent glass or horn. Through the epipyrus a pipe is to be let down to the base of the altar, where it is to revolve on an iron pin, the other end being passed through a tubular fitting attached to the epipyrus. And this pipe is to have other little cross pipes attached to it, and perforated, so as to communicate with it, (which are to radiate opposite to one another around it,) and turned alternately in opposite directions in the ends. There shall likewise be a drum attached to it, upon which the figures of the dance are to be set. Then, by the action of the kindled fire, the air, being warmed, will proceed into the pipe, and, from

it being driven out through the bent tubes in the base of the altar, will turn round the pipe and its drum."

Fig. 6.

The following is probably the most excellent of all Hero's apparatus, inasmuch as in it the action of steam produced by fire from water is employed for the purpose of elevating a fluid above its level, and transferring it from one place to another. The design of the apparatus is still, unhappily, to serve the purposes of superstitious worship. "The fire of an altar having been lighted, two figures of living things are to assist at the sacrifices, and the figure of a dragon is to sybillate," (or give forth sounds to be interpreted as oracles.)

"There is to be a hollow basis or pedestal $\alpha\ \beta$, (fig. 7,) upon which is set the altar γ, having a tube $\delta\ \varepsilon$ descending to the middle of the basis, and there separated into three branches; the tube $\varepsilon\ \zeta$ passing to the mouth of the dragon, the tube $\varepsilon\ \theta\ \varkappa$ being carried to the vessel $\varkappa\ \lambda$ containing wine, and placed at the top of the figure μ, and accurately joined into its cover; and into the third tube $\varepsilon\ \nu\ \varrho$, which, in like manner, ascends into ϱ, another vase holding wine, and is also accurately united to the top of the vase. Both ends of the two vases are to be carefully closed. There are to be in both the wine vessels

Fig. 7.

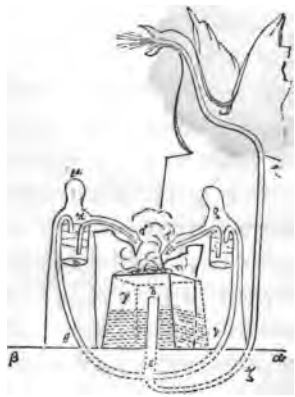


Fig. 8.

bent syphons $\varrho\ \sigma\ \tau\ \varkappa$, of which the one extremity is in the wine, and the other extremities, proceeding by an opening rendered perfectly close through the covers of

the vases, are conducted to the hands of the figures officiating at the sacrifice. When, therefore, you are about to sacrifice, you must pour into the tubes a few drops lest they should be injured by heat, and attend to every joint lest it leak; and so the heat of the fire, mingling with the water, will pass in an aerial state through these tubes to the vases, and, pressing on the wine, make it pass through the bent syphons, until, as it flows from the hands of the living creatures, they will appear to sacrifice as the altar continues to burn, and the other tube being carried to the mouth of the dragon, will make it give forth sybilline sounds."

There appears to be considerable reason to suppose that, to their knowledge of the mechanical powers and the elements of machinery, the Egyptians added some acquaintance with the power of steam, applied, however, only to the degraded service of superstition. The statue of Memnon is said to have emitted sounds which Pausanias compares to those produced by the snapping of the strings of a harp. Strabo expressly states that he heard them; and Philostratus states, that when the sun shone strongly on the statue, sounds proceeded from its mouth similar to those of a stringed instrument. Hero of Alexandria in his *Pneumatics*, Salomon de Caus in his *Raisons des Forces Mouvantes*, Athanasius Kircher in his *Œdipus Egyptiacus*, and Cribellus in his *Machinosa Miracula Memnonis*, have all explained in different ways the mechanical arrangements by means of which effects of this kind might have been produced from the steam raised by the heat of the sun in close vessels contained in the statue, and having communication with organ pipes of different kinds.

The Romans appear to have done little for the mechanical arts, and nothing for the improvement of steam apparatus. It was not until the dawn of knowledge succeeded the darkness of the middle ages, that the light reflected from the works of Hero, and the older mechanicians, rekindled the flame of mechanical invention. The works of Archimedes and of Hero were read with great avidity, and formed some of the most popular productions of the young art of printing. The flame seems first to have been lighted in Italy, for we have editions and translations of Hero's *Pneumatics* rapidly succeeding each other; the Bologna edition of 1547, translated by Giovanni Baptista Aleotti, was reprinted at Ferrara in 1589; Commandine's translation was published in 1575, Alessandro Giorgi's in 1592. There were other editions of less note; and thus in a single century eight or nine editions were issued. It was not to be expected that the seeds of mechanical knowledge, so widely sown, should not fall on some rich spots of soil, where they should bring forth fruit with increase.

Giambattista della Porta was one of the ablest and most ingenious expositors of the principles of pneumatics. A work which he published on this subject contains the following passage:—"Make a box of glass or tin, having at the bottom an aperture, through which is inserted the neck of a distilling flask, containing one or two ounces of water, and let its neck be cemented into the bottom of the box, that there be no escape. About the bottom of the box let there rise up a pipe at such a distance from the bottom as to permit the water to escape, which pipe passing through the cover shall rise a little way above its surface. The box is to be filled with water

by an aperture which is to be well closed, so that no air may pass. Finally, place the said bottle on the fire, and heating it slowly, the water being gradually dissolved into air, will press upon the water in the case, and pressing with great force upon the water which issues through the pipe (the steam,) will not make its escape. And if we continue the application of heat, the whole of the water (in the flask) will be at last exhausted; and while the water is evaporating, the air (vapour or gas) will constantly press on the water in the vessel, and the water will continually issue out. The exhalation being finished, if you will measure how much water is out of the box; that which is in the place of the water gone out, will give the measure of the remaining water. Thus you find, from the quantity of water used, how much water was dissolved into so much air. And, in like manner, also, you can measure into how much of more rarefied air, air of the ordinary density can be dissolved." *

Here we perceive that the knowledge of the conversion of water into air or gas, taught by Hero's *Pneumatics*, was extending itself in that country, and leading to further contrivances; and we have also a beautiful and simple experiment, designed for the purpose of determining the philosophical question, which formed an interesting subject of research at a very recent period of physical enquiry, "how much aqueous gas is formed by a given quantity of water." The method is not perfect, for a considerable part of the vapour would be reconverted

[1] J. B. Portæ Pneumaticorum libri tres. Neapoli, 1601, 4to.

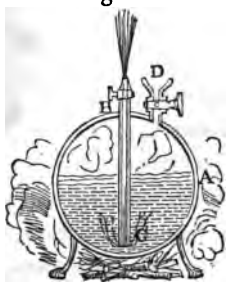
into water in the progress of the experiment; yet it shows an acquaintance with the fact, that water heated by fire is converted into aqueous air with sufficient force to raise water above its level, and form a running stream, although, in this case, of no very considerable height.

The spirit of invention, aroused by the first translation of Hero's works, did not confine itself to the country in which these works were first disseminated, but spreading gradually northwards, displayed itself in the works of an architect and engineer, Salomon de Caus, who had come to England in 1612, and was employed by the Prince of Wales, afterwards Charles I., to design grottoes, fountains, and other hydraulic ornaments, for the embellishment of the prince's palace at Richmond, and for the gratification of his Royal Highness's "gentille curiosité." These, with other machines, were published by him in a work entitled "*Les Raisons des Forces Mouvantes*, avec diverses machines tant utiles que plaisantes; auxquelles sont adjointes plusieurs desseins de grottes et fontaines, augmentées de plusieurs figures." Frankfort, 1615, fol.

The work of De Caus is prefaced by an exposition of the principles of hydrostatics and pneumatics, evidently derived from the writings of Archimedes and of Hero. Among other things, he states that the violence with which water is dissolved into air by means of fire is very great, and that it is quite certain that a ball of copper containing water, if placed on a fire, would be infallibly burst. "La violence est grande quand l'eau s'exhale en air par le moyen du feu . . il est certain que si

l'on met la dite balle sur un grand feu, en sorte qu'elle devienne fort chaude, il se fera une compression si violente que la balle crevera en pièces."

Fig. 9. Fig. 10.



De Caus's Diagram. *Hero's Diagram.*

He afterwards proceeds to show how a jet of water may be made to rise above its level, and play in the air by means of fire. A copper ball A, (fig. 9,) has a tube D, furnished with a stop-cock, by which water is forced in and it is then closed. Another tube, B C, is closely fitted to the same ball, but passes down to the bottom, where it opens amongst the water; a stop-cock regulates its opening, and immediately above the cock the pipe terminates in the orifice of a small jet d'eau. In fact, the apparatus is precisely that which Hero uses for raising a jet d'eau, but without using the action of heat, when he forces air above the water, and condensing it, raises a jet of water by its pressure, (as exhibited in fig. 10.) Of course, the heat of the fire produces the same elastic force in De Caus's machine, by which the jet is made to play in Hero's.

There seems no reason to doubt that Salomon de Caus was a Frenchman by birth, and he is said to have been a native of Normandy.* In dedicating to the French

* Biographie Universelle, tom. vii. p. 433.

monarch an edition of his work, he describes himself as one of his Majesty's subjects. After leaving England, he settled in Germany, where the Elector Palatine intrusted him with the superintendence of his buildings and of his gardens. He finally returned to France, and died there about the year 1630. He has sometimes been confounded with Isaac de Caus, a native of Dieppe, and a descendant of the same family. The latter published a work, entitled, "*Nouvelle Invention* de lever l'Eau plus haut que sa source, avec quelques machines mouvantes par le moyen de l'eau, et un discours de la conduit d'icele." Lond. 1644, fol. This work contains many machines identical with those described by Salomon de Caus; and the similarity of subject, treatment, and title of the two, has led those into much confusion who may not have examined both. Even the pains-taking and industrious Stuart seems to have been deceived, and calls Isaac's book a later edition of Salomon's.

The direct emission of steam from an orifice of the boiler, which had been used by Hero to sustain the ball in the air, was applied by Branca, an Italian architect and engineer, to impress a revolving motion on the vanes of a wheel like a common mill-wheel, and this communicating with a series of toothed wheels to a series of pestles in mortars, was employed to give them motion. This, and many other machines of which he does not claim the original invention, but which he states he collected from the inventions of others, were published in a quarto volume, entitled *Le Machine.* "Volume nuovo et di molto artificio da fare effetti maravigliosi si tanto spiritali quanto di animale operatione: arrichito di bellissime figure conle dichiarationi a ciascuna di esse in lingua volgare et Latina, del Sig. Giovanni Branca, cittadino Romano, in-

gegniero et architetto della sta. casa di Loretto. In Roma, M.DC.XXIX." This period appears to have teemed with curiosities of mechanical invention; and the learned virtuoso who would take the trouble of ransacking the mechanical productions of the sixteenth and seventeenth centuries, would be able to collect materials for an interesting, curious, and amusing volume. Perpetual motions were very common; wings for enabling men to fly in the air, mechanical chariots for a similar purpose, conveyances to the moon, and engines for making continual and cheap music by mills or by fire, for rocking of cradles and turning of spits, were favourite subjects of design; and many of these curious contrivances, without serving any definite purpose, form elegant and curious pieces of apparatus. We are now passing from the era of the curiosities of mechanical contrivance, into that period in which the same principles that actuated the toys of Hero and the automata of Kircher were to be applied to set in motion mighty machines for the advancement of the welfare of the human race.

2. *The Era of Worcester.*

EDWARD SOMERSET, Earl of Glamorgan and Marquis of Worcester, invented and constructed the first steam-engine. His title to this honour has been the subject of dispute, some historians attributing to him a greater share of merit than there was sufficient evidence to warrant, while others deprive him of even that honour to which he possesses an indefeisible claim. His life is one of the most romantic chapters of English history. Enterprising, generous, disinterested, and confiding, he was at once beloved and betrayed by his king, loaded with honours

and reduced to poverty; at one time exercising almost without control the functions of the sovereign, conferring dignities from the rank of marquis down to baronet, and at another thrown into prison, and begging from a creditor the paltry loan of five pounds. Possessing inventive genius of the highest order, he was considered a mad enthusiast because his speculations were advanced far before the age in which he lived, and he has been set down a quack and impostor by men incapable of comprehending the nature or appreciating the value of his creations. The slow march of knowledge and of time has at last revealed the worth, and established the character, of an illustrious and unfortunate man of genius, who only lived to complete his mighty design and carry it happily into effect, and having done his work, went to take his rest in death.

That the Marquis of Worcester was acquainted with the nature and force of steam, no one has ever disputed; but it has been matter of serious doubt whether the machine which he has described had ever any real existence. Hitherto we have had nothing more than circumstantial presumptive evidence of the actual construction of the marquis's steam-engine. It is only a few years since the industry of the indefatigable antiquary Robert Stuart has presented us with an historical document of undoubted authenticity, affording undeniable proof of the existence and efficiency of one of the engines of the Marquis of Worcester, of more than two horse power, employed for raising water on the Vauxhall side of the river Thames. As the Marquis's title to the invention has not yet been established in any of the numerous treatises on the steam-engine that have hitherto appeared, and as the proof we are now able to adduce must for ever set at rest the querulous cavillings

of those otherwise respectable writers who have attempted to controvert the great truth that the steam-engine is a machine wholly of British invention, we shall give a short account of what the marquis undoubtedly accomplished.

We are principally indebted for our acquaintance with the mechanical inventions of the Marquis of Worcester to a work in which he published a list of one hundred of his mechanical inventions, under the title of "A Century of the Names and Scantlings of such Inventions as at present I can call to mind to have tried and perfected, which (my former notes being lost) I have, at the instance of a powerful friend, endeavoured now, in the year 1655, to set these down in such a way as may sufficiently instruct me to put any of them into practice." Lond. 1663, 12mo. Of this remarkable work there are several other editions. The following are the passages which have immediate reference to the high-pressure steam-engine which he had invented and made. It may be proper to premise, for the purpose of preventing the supposition from being entertained that it was impossible to get devices of so complex a nature carried into effect at a period when the mechanical arts of construction had made so little progress, that he had employed constantly in his service, during a period of five-and-thirty years, one of the most eminent artificers of the time, one Caspar Kaltoff, and that he had provided him with suitable workshops, tools, and machinery, at an expense of more than ten thousand pounds. It thus appears that the marquis was no mere schemer, but that he submitted his devices to the test of experiment; and it is merely not passing

the bounds of credibility to suppose, that, with fertile resources, an active and inventive mind, the best tools, an "unparalleled" artificer, and the expenditure of great sums of money, he had in five-and-thirty years constructed machines of such perfection as no other artist of his age had accomplished, and few of the hangers-on of a royal court could understand or appreciate. No one who is acquainted with the modern high-pressure steam-engine can fail to recognise it in the following specification, which, be it observed, was given by the marquis rather for the purpose of exciting curiosity than gratifying it—for stating the capabilities of his engine than explaining its principle, which he wished to keep secret for the purpose of obtaining a patent.

"Invention 68.—An admirable *most forcible way to drive up water by fire;* not drawing or sucking it upwards, for that must be, as the philosopher calleth it, 'infra sphæram activitatis,' which is but at such a distance, *but this way hath no bounder, if the vessels be strong enough; for I have taken a piece of a whole cannon,* whereof the end was burst, and filled it three quarters full, stopping and screwing up the broken end, as also the touch-hole, *and making a constant fire under it; within twenty-four hours it burst and made a great crack:* so that, having found a way to make my vessels so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water run like a *constant fountain forty feet high.* One vessel of water, rarefied by fire, driveth up forty of cold water; and a man that attends the work is but to turn two cocks, that one vessel of water being consumed, another begins to

to force and refill with cold water, and so successively."

The internal evidence of the truth of this description is too strong to be resisted. We cannot say what ideas it may have suggested to such a man as Lord Orford, who was probably as ignorant of mechanical principles as he was devoid of candour and charity to a man of principles and religion different from his own; but to any one conversant with the mechanical contrivances and treatises even of that time, it was scarcely possible to read the sentence without forming a distinct conception of a similar apparatus to that here described by the marquis. We shall see that the description was so perfect as to enable a subsequent mechanician to reconstruct the machine of the marquis, with some additions, and produce an effective machine for draining mines. We see, too, how philosophical was the process by which he advanced to the construction of his machine. He made experiments of a conclusive nature on the boundless force of steam. He found that the only impediment to its use was the want of sufficiently strong boilers; and his having found a way to make his vessels so as to be strengthened by the force within them, merely shows that he overcame the difficulty of making steam-tight joints by using internal flanges, which should become tightened by the pressure of steam within them. There is also internal evidence of the genuineness of his description in the statement of the quantity of water converted into steam for the effect of raising the water,—"one vessel rarefied by fire driveth up forty of cold water," is a measure of the power of steam far within the compass of its capability. Even under most unfavourable circum-

stances, an unprincipled exaggerator would not have contented himself with this moderate statement of its actual power.

But we have not yet concluded the marquis's description of the nature of his stupendous prime-mover; for his mind, in dwelling upon its principles, applications, and powers, gradually became assured that his engine was to become the most important and powerful agent in the whole world, and appears, even at that remote era, to have obtained a glimpse of the multifarious avocations and powers of the modern steam-engine. He proceeds to describe "an engine so contrived, that working the *primum mobile* forward and backward, upward or downward, circularly or cornerwise, to and fro, straight upright or downright, yet the intended operation continueth and advanceth, none of the motions above mentioned hindering, much less stopping the other, but unanimously and with harmony agreeing, they all augment and contribute strength unto the intended work and operation; and therefore I call this a semi-omnipotent engine, and do intend that a model thereof be buried with me."

"How to make one pound weight to raise an hundred as high as one pound falleth, and yet the hundred pound descending doth what nothing less than one hundred pounds can effect."

"Upon so potent a help as these two last-mentioned inventions, a water-work is, by many years' experience and labour, so advantageously by me contrived, that a child's force bringeth up, an hundred foot high, an incredible quantity of water, even two foot diameter, so naturally, that the work will not be heard into the next room; and with so great ease and geometrical symme-

try, though it work day and night from one end of the year to the other, it will not require forty shillings' reparation to the whole engine, nor hinder one day's work; and I may boldly call it the most stupendous work in the whole world; and not only with little charge to drain all sorts of mines, and furnish cities with water, though never so high seated, as well as to keep them sweet, running through several streets, and so performing the work of scavengers, as well as furnishing the inhabitants with sufficient water for their private occasions, but likewise supply rivers with sufficient to maintaine and make them portable from towne to towne, and for the bettering of lands all the way it runs, with many more advantageous and yet greater effects of profit, admiration, and consequence; so that, deservedly, I deem this invention to crown my labours, to reward my expenses, and make my thoughts acquiesce in the way of further inventions."

To any one who is familiar with the advantages which such cities as London derive at this moment from having the water raised up by fire and distributed through the highest houses for private use; who has witnessed the incredible quantity of water brought up by a Cornwall, or Newcastle, or Staffordshire steam-engine from enormous depths, by the descent of a piston not one thousandth part of the weight which it raises through an equal height; who has observed the elastic force of steam as a *primum mobile* in a cylinder performing in any and every position its multifarious duties, and that a child's force is sufficient to control and guide the operation of that stupendous power, it must be most obvious that we have only carried to perfection that engine which the Marquis of Worcester first conceived and made.

Some points in the statement of the marquis, which had not formerly been noticed, have received considerable elucidation, by a manuscript account of his inventions, discovered a few years ago by Mr Robert Stuart, and by another document, of no small importance in this question, which was brought to light by the zeal and industry of the same writer, viz. a Diary of Cosmo de' Medici, Grand Duke of Tuscany, who visited England about the year 1656, in which he gives an account of the engine invented by the Marquis of Worcester, which he had an opportunity of witnessing in operation at Vauxhall.

The Condensing Steam-Engine of Captain Savary.

About thirty years after the marquis's death, which happened in 1667, the condensing steam-engine was invented by an Englishman, Captain THOMAS SAVARY, and was by him introduced for draining mines, raising water for buildings and gardens, and generating a revolving mechanical power. He exhibited a model of it to the Royal Society of London in 1699. (*Phil. Trans.* vol. xxi. p. 228.) We have seen that the marquis's model appears to have been placed on or below the level of the water to be raised, and that his vessels being filled, their contents were raised by the elastic force only of the steam. Mr Savary, on the other hand, erected his engine at a height of nearly thirty feet above the level of the water. A large close vessel was filled with steam; this steam was reconverted, by cooling the outside of the vessel, into water, leaving the large space it had formerly occupied vacuous; into this vacuum water was raised, as into the vacuum of a common sucking-pump, by atmospheric pressure, and so within the limit of atmospheric pressure, raised twenty-

eight or thirty feet. After this was accomplished, the water was further raised through any remaining height by the elastic force of the steam, just as in the engine of the Marquis of Worcester. But the improvement was great. The same force of steam, strength of vessels, and consumption of fuel which was sufficient on the marquis's plan to raise water thirty feet high, would be capable first of drawing up the water thirty feet, and then raising it thirty feet more; or doing double the work, or sixty feet of height on Savary's plan. This was certainly a notable improvement.

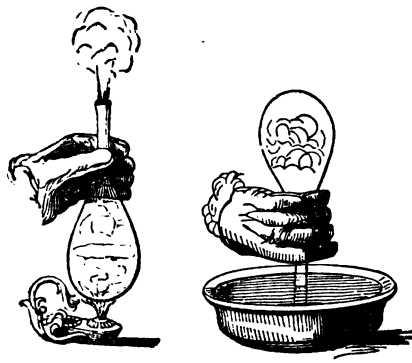
There has been considerable discussion among the historians of mechanics regarding the merits of Worcester and of Savary. Those who have thought proper to praise the inventive talent of the one, have thought it essential to their purpose to depreciate the merit of the other. We think their claims rest on independent grounds. The Marquis of Worcester expressly disclaims the use of a vacuum, which, on the other hand, is the distinguishing feature of Captain Savary's, when he says, "not by drawing or sucking it upward, for that must be as the philosopher calleth it, *infra sphæram activitatis*, which is but at such a distance; but this way (by high-pressure) hath no bounder, if the vessels be strong enough." It appears, therefore, to us, that the inventions were quite independent and different; and we have no hesitation in admitting it as exceedingly probable, that when Captain Savary added the principle of high-pressure to his own principle of a vacuum from condensation, he was not unacquainted with the marquis's works, and even with his engine for raising water by fire, for which he had obtained a patent, and which he had erected at Vauxhall. While we

have thus expressed our own opinion of the independence of their claims, we must not omit the opinions of others who lived nearer to the epoch of these rival candidates.

Dr Desaguliers, an eminent mechanist, and an experimental philosopher of considerable reputation, has given, in his *Course of Experimental Philosophy*, vol. ii., an account of the "fire-engine," and after adverting to the claims of the Marquis of Worcester, makes the following statement in regard to Savary:—"Captain Savary having read the Marquis of Worcester's book, was the first who put in practice the raising water by fire, which he proposed for the draining of mines. His engine is described in Harris's *Lexicon*, (see the word ENGINE,) which, being compared with the Marquis of Worcester's description, will easily appear to have been taken from him; though Captain Savary denied it, and the better to conceal the matter, bought up all the Marquis of Worcester's books that he could procure in Paternoster Row and elsewhere, and burn'd 'em in the presence of the gentleman, his friend, who told me this. He said that he found out the power of steam by chance, and invented the following story to persuade people to believe it, viz., that having drunk a flask of Florence at a tavern, and thrown the empty flask upon the fire, he called for a bason of water to wash his hands; and perceiving that the little wine left in the flask had filled up the flask with steam, he took the flask by the neck and plunged the mouth of it under the surface of the water in the bason, and the water of the bason was immediately driven up into the flask by the pressure of the air. Now, he never made such an experiment then, nor designedly afterwards, which I thus prove: I made the experiment purposely with about half a glass

of wine left in a flask, which I laid upon the fire till it boiled into steam; then putting on a thick glove to keep the neck of the flask from burning me, I plunged the mouth of the flask under the water that filled a bason; but the pressure of the atmosphere was so strong, that

Fig. 11. Fig. 12.



Dr Desaguliers's Experiment.

it beat the flask out of my hand with violence, and threw it up to the ceiling. As this must also have happened to Captain Savary, if ever he had made the experiment, he would not have failed to have told such a remarkable incident, which would have embellish'd his story."

We have performed the doctor's experiment frequently, with various results. If the mouth of the flask happens to be large and its neck short, the water very cold, and the flask very perfectly filled with steam, the effect is exactly what Desaguliers describes; for the vacuum being suddenly and completely formed, the flask is first pressed down towards the basin, which the hand resists by sustaining the flask in the opposite direction, and just then

the water rushes with great velocity up into the vacuum, and striking on the bottom of the flask, now turned upwards, is apt to knock it suddenly out of the hand, especially when held merely by a soft glove. But if, on the other hand, the flask has a narrow mouth and long neck, and if, when inverted, its neck be allowed to rest on the bottom of the vessel, and if the water in the basin be not very cold, it will rise slowly and gently, and the flask will be completely filled.

The doctor's inference is not, therefore, perfectly just to Savary; and allowing that Savary had read Worcester's book, he would not find in it any principle of this nature, but an express exception from it, as we have already stated.

Stephen Switzer, author of a *System of Hydrostatics and Hydraulics*, published at London in 1729, takes a different view of the matter. In the chapter "On the Engine for raising Water by Fire," he gives the following account of it:—"Amongst the several engines which have been contrived for the raising of water for the supply of houses and gardens, none has been more justly surprising than that for the raising of water by fire; the particular contrivance and sole invention of a gentleman with whom I had the honour, long since, to be well acquainted—I mean the ingenious Captain Savary, some time since deceased, but then a most noted engineer, and one of the Commissioners of the sick and wounded.

"This gentleman's thoughts (as appears by a preface of his to a little book entitled *The Miner's Friend*) were always employed in hydrostatics or hydraulics, or in the improvement of water-works; and the first hint from which it is said he took this engine, was from a tobacco-

pipe, which he immersed to wash or cool it, as is sometimes done. He discovered that the water was made to spring through the tube of the pipe in a wonderful and surprising manner; though others say that the learned Marquis of Worcester, in his *Century of Inventions*, (which book I have not seen,) gave the first hint for this raising water by fire.

"It was a considerable time before this curious person, who has been so great an honour to his country, could bring this his design to perfection, on account of the awkwardness of the workmen who were necessarily to be employed in the affair; but at last he conquered all difficulties, and procured a recommendation of it from the Royal Society, (*Phil. Trans.*, 252,) and soon after a patent from the Crown, for the sole making this engine; and I have heard him say myself, that the very first time he play'd, it was in a potter's house at Lambeth, where, though it was a small engine, yet it (the water) forced its way through the roof, and struck up the tiles in a manner that surprised all the spectators."

"About the year 1699, he wrote a small pamphlet or treatise concerning this engine which I have just now mentioned, wherein he has exhibited a draught of it; but as that consisted of a double receiver, and a great many particulars not so easy for a learner at first sight to understand, I have, first of all, inserted that draught of it, and the account thereof, which Mr Bradley, in his *New Improvements of Planting and Gardening*, has given us of that at Cambden House, it being an engine of Mr Savary's own invention, and which is the plainest and best proportioned of any that I have seen.

"A the fire; B the boiler, a copper vessel of a sphe-

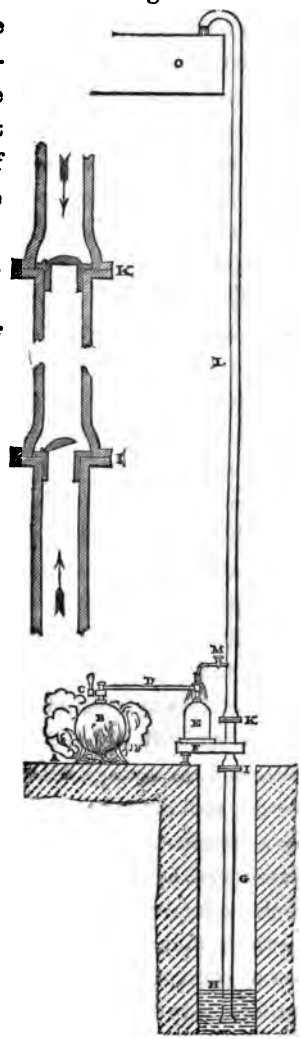
rical figure in which the water is boiled and evaporated into steam, which passes through the regulator C, which opens to let it into D the steam-pipe, of copper, through which it descends into E the receiver, which is a vessel of copper also, that at first setting to work is full of air, which the steam discharges through F the engine tree, and up the clack valve at K, and so the air ascends in L the force pipe.

"After E is void of air, which is found by its being hot (with steam) all over, then stop the steam at C, and throw a little cold water on the outside of the hot receiver E, so as to cool down the steam in the inside, and so make it resume the condition of water, leaving E a vacuum, into which the pressure of the atmosphere will raise a column of water through the sucking pipe G from H, the pond, well, or river.

"This being done, and the receiver now being filled with water, first turn C, and let the steam pass into the receiver E, and it will force the water therein through F by K up to L, which water cannot descend because of the clack valve I. When E is thus emptied, which may be easily perceived by its being hot, as before, turn C, and confine your steam in B, then open the cock M, which will let a little cold water into E, and that, by condensing the steam in E, will cause the water to ascend immediately from H and replenish E. Then turn C to let the steam into E, and it will force the water out of it up L, into a cistern at O, placed at the top to receive it. Then confine your steam at C as before, and turn M for the space of a second or two of time, and E will be refilled, and may again be discharged up L as before; so that this work may be continued as long as you please. The valves placed

in the pipes at I and K are shown on a larger scale at the side, and will enable the reader to see how they permit the water to ascend, but prevent its return by the weight of the water pressing down the clack.

Fig. 13.



"It must be noted that this engine is but a small one in comparison of many others of this kind that are made for coal-works; but this is sufficient for any reasonable family, and other uses required for it in watering all middling gardens. Its dimensions are as follows:—the pipe from the surface of the water to F is 16 feet, and from F to the upper cistern 42 feet high; the diameter of both pipes 3 inches, and of the steam-pipe D, an inch. The receiver E holds 13 gallons of water, and the boiler three times that quantity.

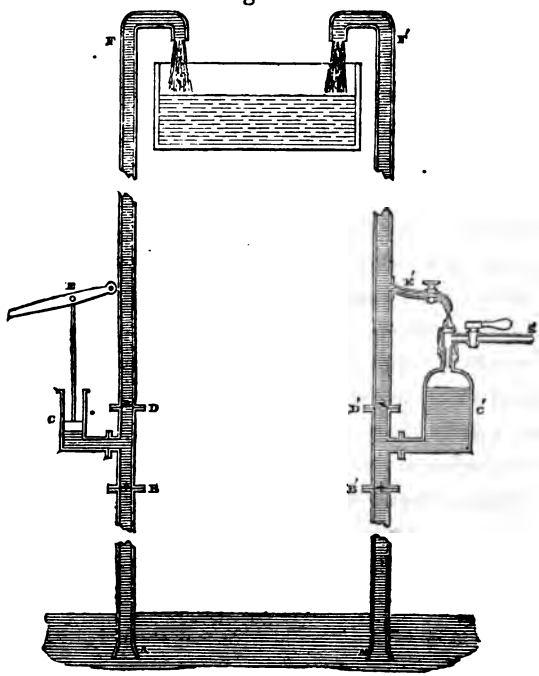
"This engine will throw up four of the receivers full in one minute=52 gallons, which is 3110 gallons an hour, =52 hogsheads an hour, or

1248 hogsheads in 24 hours. The prime cost of such an engine is about L.50, as I myself have had it from the ingenious author's own mouth, and the quantity of coals required to work it about one bushel in twenty-four hours. The expense is not considerable to what horse-work is, which must be shifted twice or thrice a-day, especially in all wood or coal countries."

It seems to us very probable, from the form of Savary's engine, that it was taken directly from that of a common drawing and forcing pump, with the substitution of the force of steam only for that of the pump piston. In Fig. 14, A B C D E F represent a common forcing pump, as given in the hydraulic works of that epoch. A′ B′ C′ D′ E′ F′ are the parts of one of Savary's steam-pumps. In the case of the common pump, the solid piston or plug at C, exactly fitted to the cylindrical chamber at C, is forced down by the lever E upon the water in the chamber C, which is pressed out through the pipe at the bottom, and being prevented from passing down to A by the closing valve B, is carried up through the open valve D, and raised towards the top of the reservoir F. When the chamber C is thus emptied, the piston is again raised, and as it is perfectly tight, so that no air can enter, the water is carried up through the valve B, which only opens upwards, and thus the vacuum at C is filled from below, by atmospheric pressure, with water, which is again to be forced back by the descent of the piston; but as the valve B closes by the pressure above it, and the valve D opens upwards, the water is carried upwards and delivered at F, the top of the reservoir. For the solid piston of the pump we have only to substitute the agency of steam, and we have Savary's machine. The close chamber C′ being conceived

full of water, steam from the boiler is admitted by S′, and, by its elastic force, presses downwards on the surface of

Fig. 14.



the water at C′, so as to force it out of the receiver; and finding no exit by the closed valve B′, it is forced through the rising valve D′ towards the receiver F′; in these circumstances, the little jet brought from the pipe E′ is allowed to throw cold water for a second or two on the close chamber C, now filled with steam, which is immediately condensed into the small quantity of water from which it was originally formed, and leaves the remaining space vacuous—into which vacuum, as in the former case,

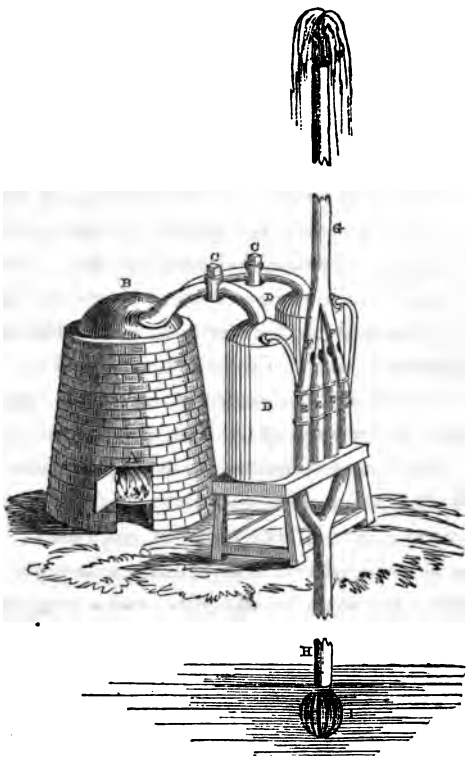
water is carried up by the force of the atmosphere, so as again to replenish the chamber C′, as at first, with water, which is in its turn to be acted on by the elastic force of steam admitted through S′, and carried up through D′ F′ to be delivered at F′.

The reader who has followed this examination of Savary's steam-engine in its earlier form, is now prepared to understand the more complex but more efficient form in which the engine was more generally used. This form is that of the double receiver. The form hitherto examined does not produce a uniform stream, because the receiver, after having emptied its contents, requires a considerable interval to fill again. The double machine renders the stream nearly constant, for there are two receivers placed in communication with the boiler and the water-pipes, in such a manner that when the one is being filled the other is being emptied, and when the latter is again being charged with water from below, the other is discharging its contents in the receiver above.

In this double form, a model of the engine was exhibited to the Royal Society in June 1699, and approved of. The following figure and description are those given in the *Philosophical Transactions*, vol. xxi:—"A the furnace, B the boiler, CC two cocks which convey the steam alternately to the vessels DD, which receive the water from the bottom in order to discharge it again at the top. EEEE, valves opening only upwards; FF, cocks which keep up the water while the valves on occasion are cleansed; G the force-pipe, H the sucking-pipe, I the water." The action of this double engine is manifest. One of the vessels D is first filled with water from below, by the effect of the vacuum formed in it, and

is then discharged into the reservoir above. The steam is then shut off, and the vacuum again begins to form, and this first receiver to refill with water; in the mean time the steam would be unemployed, and therefore it is now admitted into the second receiver D 2, where it forms a vacuum, or if the receiver be filled with water, forces it

Fig. 15.



up to the top, and having emptied it, is again shut off and forms a vacuum to refill this second receiver with

water. But in the mean time, this second receiver being now vacuous, and in the process of being refilled with water from below, the steam being unemployed upon it may be admitted to the first receiver D, which has in the interval been charged with water from below, and the steam acting upon it will continue the stream into the reservoir at the top, until the other receiver, D 2, being again filled, is again ready to be discharged in the same direction, and so on as long as the cocks are turned.

But this working model of the Royal Society was by no means a perfect machine for performing work on a large scale. We have, therefore, extracted the following description of the machine of Savary, in the form which he gave it when introduced for the purpose of draining mines. The description and figure are taken from an old work in the Advocates' Library, entitled, "The Miner's Friend; or, a Description of an Engine for Raising Water by Fire, with an Answer to the Objections against it. By Thomas Savary, Gent." London, 1702.

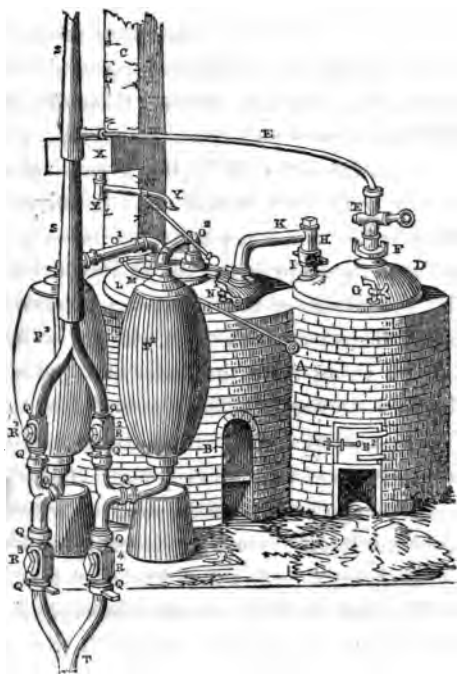
Fig. 16 represents the engine of Savary as applied to the purpose of drawing water from the bottom of deep mines. The furnaces, boilers, and receivers are placed under ground, on a platform raised sixteen or twenty feet above the level of the water at the bottom of the mine. From this platform the chimney ascends to the surface along the shaft of the mine, and a pipe through which water is forced to the surface accompanies it.

A Description of the Engine.

A the furnaces; B^1 B^2 the two fireplaces; C the funnel or chimney; D the small boiler; E the pipe and cock of it; F the screw that covers and confines the force; G

a small cock going to a pipe within eight inches of its bottom; H a large pipe going the same depth; I a clack on the top of the said pipe opening upwards; K a pipe going from the box of the said clack or valve into the great boiler about an inch into it; L the great boiler; M the screw with the regulator; N a small cock and pipe going half way down the great boiler; O^1 O^2 steam pipes, one

Fig. 16.



end of each is screwed to the regulator, and the other end to the receivers; P^1 P^2 the vessels called receivers; Q the screws which bring on the pipes and clacks into the

front of the engine; R R R R Nos. 1. 2. 3. 4. valves or clacks of brass, with screws to open and come at them upon occasion; S the force-pipe; T the sucking-pipe, having a square frame of wood, with holes round its bottom in the water; X a cistern, with a buoy-cock coming from the bottom of the said cistern; Z the handle of the regulator.

"The manner of working this engine is, first: there is a good double furnace so contrived that the flame of the fire may circulate round and encompass the two boilers to the best advantage, as you do coppers for brewing. Before you make any fire, unscrew G and N, being the two small gauge-pipes and cocks belonging to the two boilers, and at the holes fill L, the great boiler, two-thirds full of water, and D, the small boiler, quite full; then screw in the said pipes again, as fast and tight as possible; then light the fire at B, No. 1; when the water in L boils, the handle of the regulator, marked Z, must be thrust off from you as far as it will go, which makes all the steam rising from the water in L press with irresistible force through O No. I, into P No. 1, making a noise as it goes; and when all is gone out, the bottom of the vessel P No. 1 will be very hot. Then pull the handle of the regulator towards you, by which means you stop O No. 1, and force your steam through O No. 2 into P No. 2, until that vessel has discharged its air through the clack R No. 2 up the force-pipe. In the mean time, by the steam's condensing in the vessel P No. 1, a vacuum of emptiness is created, so that the water must and will necessarily rise up through T, the sucking-pipe, lifting up the clack R No. 3, and filling the vessel P No. 1.

"In the mean time, the vessel P No. 2 being emptied of its air, turn the handle of the regulator from you again, and the force is upon the surface of the water in P No. 1; which surface being only heated by the steam, it does not condense it, but the steam gravitates or presses with an elastic quality like air, still increasing its elasticity or spring, till it counterpoises or rather exceeds the weight of the water ascending in S, the forcing pipe, out of which the water in P No. 1 will be immediately discharged, when once gotten to the top; which takes up some time to recover that power, which having once got and being in work, it is easy for any one that never saw the engine, after half an hour's experience, to keep a constant stream running out the full bore of the pipe S. For on the outside of the vessel P No. 1 you may see how the water goes out, as well as if the vessel was transparent; for as the steam continues within the vessel, so far is the vessel dry without, and so hot, as one is scarce able to endure the least touch with one's hand; but so far as the water is, the said vessel will be cold and wet, where any water has fallen on it; which cold and moisture vanishes as fast as the steam in its descent takes place of the water. But if you force all the water out, the steam, or a small part thereof, going through R No. 1, will rattle the clack, so as to give sufficient notice to pull the handle of the regulator to you, which at the same time begins to force out the water from P No. 2, without the least alteration of the stream; only sometimes the stream of water will be somewhat stronger than before, if you pull the handle of the regulator before any considerable quantity of steam be gone up the clack R No. 1; but it is much better to let none of the steam

go off, (for that is but losing so much strength,) and is easily prevented by pulling the regulator some little time before the vessel forcing is quite emptied. This being done, immediately turn the cock or pipe of the cistern X on P No. 1, so that the water proceeding from X, through L Y, (which is never open but when turned on P No. 1 or P No. 2, but when between them is tight and stanch;) I say, the water falling on P No. 1 causes by its coolness the steam (which had such great force just before, by its elastic power) to condense—to become, in the language of our author, 'a vacuum or empty space.' So that the vessel P No. 1 is, by the external pressure of the atmosphere, or what is vulgarly called suction, immediately refilled while P No. 2 is emptying; which being done, you push the handle of the regulator from you, and throw the force on P No. 2, causing the steam in that vessel to condense, so that it fills while the other empties. The labour of turning these two parts of that engine, viz. the regulator and water cock, and tending the fire, being no more than what a boy's strength can perform for a day together.

"The ingenious reader will probably here object, that the steam being the cause of this motion and force, and that steam is but water rarefied, the boiler L must be in some certain time emptied, so as the work of the engine must stop to replenish the boiler, or endanger the burning out or melting the bottom of the boiler.

"To answer which, be pleased to observe the use of the small boiler D, when it is thought fit, by the person tending the engine, to replenish the great boiler, (which requires an hour and a half, or two hours' time to the sinking one foot of water.) Then I say, by turning the cock of the small boiler E, you cut off all communication

between S the great force-pipe and D the small boiler, by which means D grows immediately hot; by throwing a little fire into B No. 2, the water of which boils, and in a very little time it gains more strength than the great boiler; for the force of the great boiler being perpetually spending and going out, and the other winding up and increasing, it is not long before the force in D exceeds that in L; so that the water in D being depressed in D by its own steam or vapour, must necessarily rise through the pipe K into L, running till the surface of the water in D is equal to the bottom of the pipe H.

"Then the steam and water going together, will, by a noise in the clack I, give sufficient assurance that D has discharged and emptied itself into L, to within eight inches of the bottom. And inasmuch as from the top of D to the bottom of its pipe H is contained about as much water as will replenish one foot; so you may be certain it is replenished one foot—of course then you open the cock I, and refill D immediately.

"By which you will see that there is a constant motion, without fear or danger of disorder or decay; and if you would at any time know if the great boiler L be more than half exhausted, turn the small cock N, whose pipe will deliver water, if the water be above the level of its bottom, which is half way down the boiler; if not, it will deliver steam.

"So likewise will G show you if you have more or less than eight inches of water in D; by which means nothing but a stupid neglect or mischievous design carried on some hours, can any ways hurt the engine. And if a master is suspicious of the design of a servant to do mischief, it is easily discovered by those gauge-pipes. For

if he comes when the engine is at work, and finds the surface C of the water in L below the bottom of the gauge-pipe N; or the water in D below the bottom of G, such a servant deserves correction, though three hours after that, the working on could not damage or exhaust the boiler. So that, in a word, the clacks being in all water-works always found the better the longer they are used; so here the same effect is found, and all the moving parts of the engine being of like nature, the furnace being made of *Sturbridge* or *Windsor* brick or fire-stone, I don't see it possible for the engine to decay in many years.

"For besides, the clacks, boxes, and water-pipes, regulator and cocks, are all of brass, and the vessels are made of the best hammered copper, of sufficient thickness to sustain the force of the working engine. In short, the engine is so naturally adapted to perform what is required, that even those of the most ordinary and meanest capacity may work it for some years without injury, if not hired or employed by some base person on purpose to destroy it. For after the engine is once fixed and at work, I may modestly affirm that the adventurer or supervisor of the work will be freed from that perpetual charge, expense, and trouble of repairs which many engines are generally liable to."

One of the first uses of Savary's engine, proposed by himself, was to raise water into a reservoir, from which it should be allowed to fall on a mill-wheel, turning round the machinery in the same way as a common fall of water; and after reaching the bottom, it was again to be raised by the steam-engine to the upper reservoir, for the purpose of again descending on the wheel. We are not,

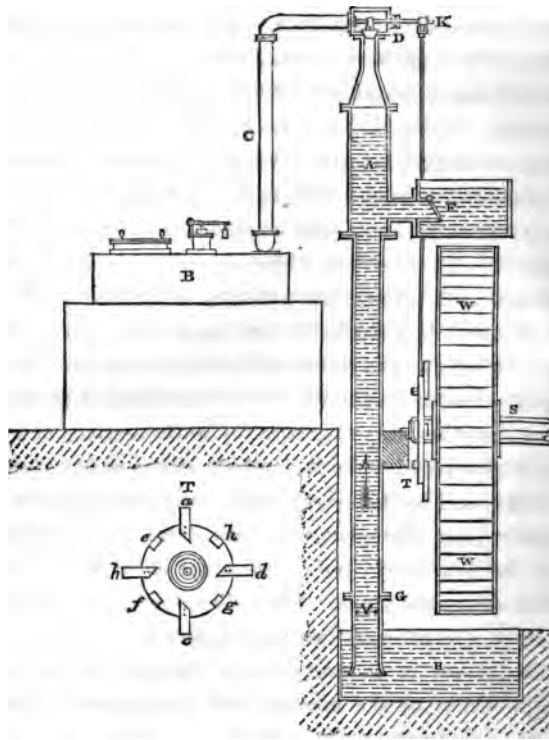
however, aware that any machine was applied in this manner during Savary's life; but after his death several of them were erected by a Mr Joshua Rigley, at Manchester, and throughout Lancashire, to impel the machinery of some of the earliest cotton-mills and manufactories of the district. One of these, of which we have here given the figure, was erected at St Pancras, London, at the manufactory of a Mr Kier, where it long continued to turn lathes, &c. We have taken the following description of it from Nicholson's *Journal.*

"The figure is the section of this engine taken through the centre. B (fig. 17) represents a boiler shaped like a waggon, seven feet long, five feet wide, and five deep; it was considered as being of dimensions sufficient to work a larger engine; a circumstance which must, in a certain degree, diminish the effects of the present one. The boiler feeds itself with water, from a cistern, elevated by a pipe which descends into the boiler and has a valve in it at the upper end, which shuts downwards, and is connected by a wire with a float on the surface of the water within the boiler, so as to open the valve whenever the water subsides below its intended level; for the float which swims on the water then sinks, and by its weight draws the valve up to allow the water from the cistern to run down the pipe, and supply the deficiency; but as the water in the boiler rises the float closes the valve. The boiler, therefore, remains constantly, or nearly, at the same degree of fulness.

"The steam is conveyed by a pipe C to a box D, through which, by the opening and shutting of a valve, it can be admitted to the cylindrical receiver A. The axis K serves as a key to open and shut the valve, which is a circular plate formed conical on the edge, and fits

in a corresponding aperture in the bottom of the box D; H is a cistern from which the engine draws its water, through a vertical suction-pipe, in which a valve G is placed, to prevent the return of the water; F is another cistern, into which the water is delivered from the receiver A, through the spout F, which is provided with a valve

Fig. 17.



opening outwards; WW represents an overshot water-wheel, 18 feet in diameter, of which the axis S commu-

nicates motion to the lathes and other machines used in the manufactory.

"The engine raises the water from the lower cistern H, by suction, into the receiver A, from which it runs into the upper cistern F, and thence flows through a sluice into the buckets of the water-wheel W, to give it motion. The water as it is discharged from the buckets of the wheel falls again into the lower cistern H. As the same water circulates continually in both the cisterns, it becomes warmer than the hand, after working a short time; for which reason the injection-water is forced up by a small forcing-pump from a well. This injection-pump is worked by the water-wheel by means of a loaded lever or pump handle, which is raised up by the motion of the wheel, and then left to descend suddenly by its weight and force up the water into the receiver. A leaden pipe passes from this forcing-pump to the upper or conical part of the receiver A, for the purpose of injecting cold water at the proper time. Neither of these could be represented with convenience in the present section.

"The manner in which the steam and cold water are alternately admitted into the receiver A, remains to be explained. Upon the extremity of the axis S of the water-wheel a solid wooden wheel T is fixed; it is about four feet in diameter, and turns round with the water-wheel. It is represented separately, as seen in the front. *a b c d* are four cleats, all or any number of which may be fixed on the wheel at a time. Each cleat has its correspondent block, *e f g h*, on the opposite surface of the wheel. The use of these is to work the engine. Thus, suppose the water-wheel and this wheel T, with

all the revolving apparatus, are turning round, one of the cleats, *a*, meets in its rotation with a lever, which it lifts up, and this opens the steam-valve D by a rod of communication reaching to the handle of the axis K. The steam consequently passes into the receiver A, and the steam-valve shuts again as soon as the cleat *a* of the wheel T has passed away from the lever by the motion of the wheel. All this time the correspondent block *e* on the other side of the wheel T had been operating to raise up the loaded lever which forms the handle of the forcing-pump. And at the same instant that the steam-valve D is shut, as above mentioned, the block *e* quits the loaded lever, after having raised it up, and leaves it to descend suddenly by its own weight. This depresses the forcer of the pump, and thereby throws a jet of cold water up into the receiver A, and it falls in a shower of drops through the steam which fills the receiver, so as to cool and condense the steam, and make a vacuum therein. The pressure of the atmosphere upon the surface of the water in the cistern H then causes the water to mount up the perpendicular suction-pipe, through the valve G, towards the exhausted receiver.

"When the engine is first set to work, the water-wheel being motionless, the steam-valve and injection-pump are moved by hand; and if the engine has been long out of work, two or three strokes may be necessary to raise the water to the top of the receiver A, so as to fill it full of water. As soon as this is the case, and the steam-valve is opened to admit steam into the receiver, the whole contents of water above the spout and valve F then flows out of the receiver A, by its own gravity, into the upper cistern R.

"The water which is thus raised is suffered to flow from the cistern upon the overshot water-wheel W, through a sluice, and by that means keeps the wheel in motion, and replenishes the lower cistern. There is no reservoir for the injection-water, but the requisite quantity is driven up at each stroke; and as this is done by the sudden descent of the loaded lever of the pump, the water is injected very suddenly into the receiver."

The Atmospheric Steam-Engine of Newcomen and Cawley.

The title of this steam-engine correctly indicates the principle of its action. The effect which it produces is not by the direct and immediate agency of steam, but of the atmosphere. All that the steam does in this machine is merely to make way for the atmosphere, and give effect to its pressure. It is therefore necessary to retrace our steps, and give some consideration to the mode of operation of atmospheric pressure as an introduction to this description. A full exposition of the nature of the pressure of the atmosphere will be found in the article Pneumatics, in the *Encyclopædia Britannica*, to which our readers are referred for a more perfect acquaintance with this subject. We shall only touch upon such branches of experiment, concerning atmospheric pressure, as are so closely intertwined with our more immediate investigation as to constitute an essential part of it.

We have merely to notice, that after the discovery of the laws of atmospheric pressure by the pupils of Galileo, we owe most of our information on the phenomena resulting from the pressure of the atmosphere, and of the apparatus constructed for exhibiting its powers on a large scale,

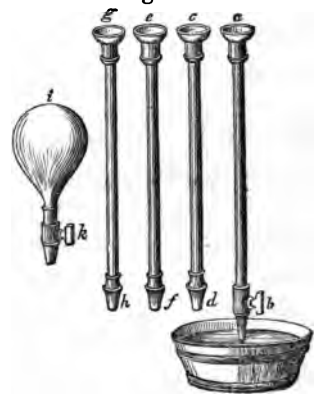
to Otto Guericke, privy councillor of his Serene Highness the Elector of Brandenburg, and consul of Magdeburg, who had in 1654 brought his pneumatic apparatus to considerable perfection, and continued to make his experiments to an advanced age. They were published by Gasparus Schottus in his work "De Arte Mechanicâ Hydraulicâ Pneumaticâ," in 1657, and again by the author himself, in a thin volume, entitled "Ottonis Guericke Experimenta Nova Magdeburgica de Vacuo Spatio, Aeris Pondere," &c. Amstelodami, 1672, fol.

We have extracted and translated the following passages of this rare work from a copy in the library of the College of Physicians at Edinburgh. They show us that the mode of raising water above its level by atmospheric pressure, and by a vacuum, was by him so clearly made known, that the use of steam as the instrument for effecting that vacuum was a very direct and easy transition. Indeed the apparatus we have first to consider is a very simple illustration of the action of Savary's machine.

Illustration of raising water by a vacuum, and the pressure of the atmosphere, taken from chapter xx. of Otto Guericke.

"Make four tubes or pipes *ab*, *cd*, *ef*, *gh*, each about eight feet long, made of glass, and mounted at the extremities with conically tapered fittings, so as to be accurately joined to each other, each joint surrounded by a small cup, into which liquid being poured, the joints may be prevented from taking in air; let there also be a stopcock on the lowest, and let there be taken a glass flask *i*, also fitted air-tight with a stopcock *k*.

Fig. 18.



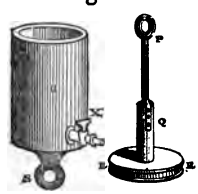
"Having joined all these tubes together, so as to form a tube erected on the wall of a house, the lower end being immersed under water in the open vessel; the large flask or receiver having been previously emptied of air by the air-pump, and being now placed on the top of the long tube, and the stopcock *k* being opened, the water will violently rush up the tube to the height of above thirty feet. The rationale is this, that the external air presses on the surface of the water in the bucket, which finds free exit from this force up the vacuous space of the tube, from which the air has been withdrawn, into the flask *i*; and settles at such a height as will balance by the weight of the column of water the weight of the circumambient air."

The reader of this very clear and accurate exposition may easily perceive that when it has once been discovered that water, after having been rarefied by heat into steam, so as to fill a large space, is afterwards condensed by cold, so as to leave a portion of that space vacuous, nothing remains to be done except to make the vacuum of the flask *i* by steam instead of an air-pump, and the machine of Savary is obtained. In fact, the flask *i* of Otto Guericke corresponds accurately to the receiver of Thomas Savary. The reader has only to understand the former, in order to perceive at a glance the action of the latter.

This first experiment of Otto Guericke, therefore, represents with fidelity the principle of Savary's engine for raising water by the formation of a vacuum. Not less beautifully does another experiment of the same philosopher exemplify the principle of the species of engine known as the atmospheric engine, or Newcomen's steam-engine. And its construction is peculiarly important at this stage of our progress, as the reader has only to take the trouble of following the details of the experiment of Guericke, in order to comprehend correctly the machine of Newcomen. In fact, all his experiments on the power of the atmosphere are admirable illustrations of the principle of the atmospheric steam-engine; so that the reader will do well to remember that the only use of the steam in the atmospheric steam-engine is to form a vacuum.

Description and operation of the atmospheric apparatus for raising great weights by a vacuum under a piston in a cylinder, exhibited amongst other experiments, at the diet of Ratisbon in 1654, to the court and their Majesties Ferdinand III. and his son Ferdinand IV, &c., chap. xxvii. and xxviii.

Fig. 19.



"A large vessel of copper, *a*, made truly cylindrical, and having its sides perfectly even and parallel, and about twenty inches high and eight inches wide, was fixed firmly in a vertical position by the strong ring S. In the next place, a piston, PQR, was made to fit exactly the inside of the aforesaid cylinder, P being of iron and Q wood, and the rounded head R, formed of the hardest oak, being hollowed out on the edge like the

pulley of a common well, in which groove flax or hemp is to be rolled round so as to fill it up, and the whole is then to be placed in the aforesaid cylinder *a*, (like as a piston and its head in a common syringe or pump for extinguishing fires,) and fitted so exactly that air can neither pass outwards or inwards through between the piston and cylinder. Thirdly, the cylinder *a* is to be attached to the great upright beam, Fig. 20, by an iron bracket, through the ring aforesaid S, and the piston PQR is to be let into the cylinder *a*, and the iron handle PQ of the piston is to be passed through the ring of a second iron arm O, in such a manner that it can play freely up and down through the whole height of the cylinder, and at the same time be steadily preserved in the straight

Fig. 20.

line, but not permitted to rise further than O. In the *fourth* place, a rope, to the end of which is firmly attached

a hook, is carried round the wheel *t*, and fastened by its hook to the piston-rod PQ, and the other end of the rope has other ropes attached to it, to be grasped by the men, as in the figure.

" Now, if the stopcock X be closed, the piston being nearly at the bottom, the joint efforts of fifty or more men will not be able to raise it more than about halfway up the cylinder.

" If, now, in the *fifth* place, the large glass receiver, formerly mentioned, which has been previously made perfectly vacuous, (by an air-pump,) be applied to the stopcock X, and then when the men are exerting their utmost force, the stopcocks at X of the vacuous receiver

Fig. 21.

and the cylinder be opened, so as to make a free communication from the one into the other; the piston PQR

will be suddenly forced down to the bottom of the cylinders in spite of the greatest efforts of the men to keep it up.

"The whole cause of this matter is to be attributed to the gravity of the air, which, when the vacuum is formed below, instantly presses down the piston into it with a force which, according to our former calculation, amounts in that size of cylinder to 2686 pounds' weight."

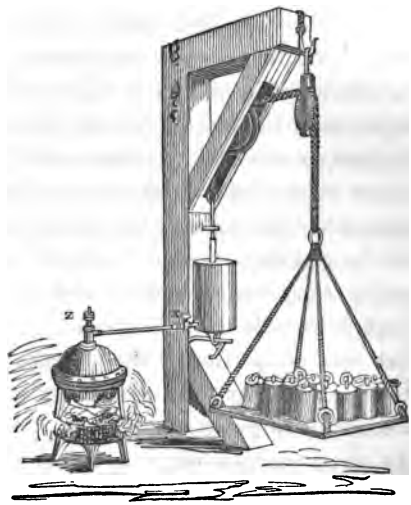
The next of the Magdeburg experiments still more closely resembles the atmospheric steam-engine in its mode of application, and still further illustrates it.

"By the above-mentioned invention, a child of twelve or fifteen years old can raise an enormous weight. Every thing being left as formerly, only the piston being nearly at the top of the cylinder *a*, you are to pass the rope round a second pulley, hung from a staple as in fig. 21; and by a hook to suspend from the rope the scale of a large balance, which you are to load with a weight of 2686 pounds. If a small syringe be applied by a little boy to the stopcock X to pump out the air, it will follow that, as the air is pumped out from below the piston, the atmosphere above will press it down and raise the weight."

The transition from this to the engine of Newcomen is immediate. To the last-described apparatus of Guericke let there be added a small copper globe or boiler, Z, Fig. 22, to be placed over a fire till the water which it contains boils into steam. This steam, entering below the piston, will occupy the whole space of the cylinder; but if now the stopcock X be suddenly closed, and especially if cold water be sprinkled on the outside of it to cool it, the steam will be condensed back into its original bulk of water, and leave the space it formerly occupied in the cylinder a vacuum,

into which the atmosphere will press down the piston P Q R, just as in the former instance, raising up the weights at the other end of the rope. This is just the atmospheric engine of Newcomen. It is the atmosphere which

Fig. 22.



does the work; the steam acts indirectly as the medium through which a vacuum is effected; and it is only the efficient agency of the atmosphere which is thus rendered useful in giving motion to a weight.

We hope that nothing which we have here said concerning the discoveries of Guericke will be misunderstood, as intended in any way to depreciate the value set upon the inventions of Mr Savary or Mr Newcomen; they are only introduced as illustrations by which we are most easily conducted to a thorough comprehension of the principles on which they act, and of the state of knowledge

of atmospheric pressure which existed at that date. The experimental apparatus of Guericke was in no respect a steam-engine; and although his speculations were divulged before the inventions of Savary and Newcomen, the agency of steam still remained to be introduced, before a machine useful to the arts and industry of man was produced.

Newcomen's Fire-Engine.—Switzer, in his *Hydrostatics*, (1729) has the following passage:—"To finish this long account of the surprising engine for the raising of water by fire, I produce this last improvement of it by Mr THOMAS NEWCOMEN, which makes it undoubtedly the beautifullest and most useful engine that any age or country ever yet produced: as the best and most useful inventions and improvements which have been discovered either in art or nature, have, in process of time, been liable to improvement, so this, of the fire-engine, has been subject to the same, for this ingenious gentleman to whom we owe this late invention, has, with a great deal of modesty, but as much judgment, given the finishing stroke to it. It is, indeed, generally said to be an improvement to Mr Savary's engine; but I am well informed, that *Mr Newcomen was as early in his invention as Mr Savary was in his*, only the latter being nearer the court, had obtained his patent before the other knew it, on which account Mr Newcomen was glad to come in as a partner to it." Dr Desaguliers, speaking of Savary's engine, also says, "these discouragements (the difficulty of making sufficient high-pressure boilers, &c.) stopped the progress and improvement of this engine till Mr Newcomen, an ironmonger, and John Cawley, a glazier living at Dartmouth, brought it to the present

form in which it is now used and has been near these thirty years." (1744.) *Experimental Philosophy*, ii. 467. And again, "about the year 1710, Thomas Newcomen, ironmonger, and John Cawley, glazier, of Dartmouth, in the county of Southampton, (Anabaptists,) made then several experiments in private, and having brought it to work with a piston, &c., in the latter end of the year 1711, made proposals to draw the water at Griff in Warwickshire; but their invention meeting with no reception, in March following, through the acquaintance of Mr Potter of Bromsgrove, in Worcestershire, they bargained to draw water for Mr Back of Wolverhampton, where, after a great many laborious attempts, they did make the engine work. They were at a loss about the pumps, but being so near Birmingham, and having the assistance of so many admirable and ingenious workmen, they soon came to the method of making the *pump-valves, clacks, and buckets;* whereas they had but an imperfect notion of them before. One thing is very remarkable. At first working, they were surprised to see the engine go several strokes and very quick together, when, after a search, they found a hole in the piston which *let the cold water in to condense the steam in the inside of the cylinder*, whereas, before, they had always done it on the outside. They used before to work with a buoy in the cylinder inclosed in a pipe, which buoy rose when the steam was strong, and opened the injection-pipe and made a stroke, whereby they were capable of only giving six, eight, or ten strokes in a minute, till a boy named Humphrey Potter, who attended the engine, added what he called *scoggan, by which the beam of the engine always opened and shut its own valves*, and then it

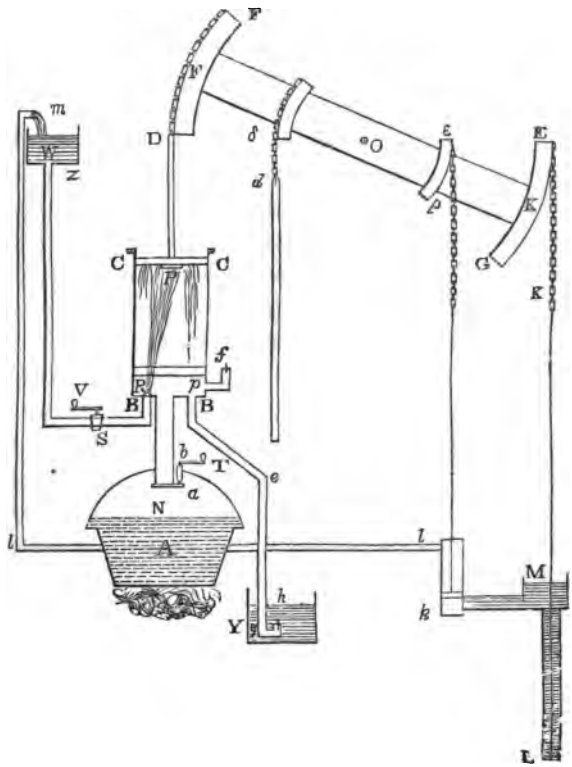
would go (entirely without the attendance of a man) fifteen or sixteen strokes in a minute. But this being perplexed with catches and strings, Mr Henry Beighton, in an engine he had built at Newcastle-on-Tyne in 1718, took them all away, *the beam itself supplying all much better.* The way of leathering the piston was found by accident about 1713. Having screwed a large broad piece of leather to the piston, which turned up the sides of the cylinder two or three inches: in working, it wore through, and cut that piece from the other, which, falling flat on the piston, wrought with its edge to the cylinder, and having been in a long time, was worn very narrow, which being taken out, they had the happy discovery whereby *they found that a bridle rein or even a soft thick piece of rope or match going round, would make the piston air and water tight.*"

This short note of Dr Desaguliers, who, with Switzer, is our authority for the historical facts of this date, contains the leading points of the history of the steam-engine as generally used for raising water during the eighteenth century. Newcomen gave to the engine a *cylinder* and *piston:* he formed *a vacuum in the cylinder below the piston,* by first admitting steam from the boiler so as to expel air and balance the pressure of the atmosphere, and afterwards *condensing the steam* so as to reduce it back to its primitive bulk of water, and thus, by leaving the space below the piston empty, allow *the pressure of the atmosphere upon the whole surface of the piston* to carry it with a force somewhat less than fourteen pounds on each inch of that surface downwards to the bottom of the cylinder, so that by suspending the piston with a chain from the end of a *rocking beam* to the

opposite extremity of which the *rod and buckets of a large draining-pump* were attached, a considerable volume of water was raised at each alternate ascent and descent of the piston, which was raised up again by the weight of the pumps and water, at the other end, whenever the steam was re-admitted below the piston to balance the atmosphere—he gave to the *valves, clacks, buckets,* &c., that *improved mechanical construction* which rendered them suitable to the precision of the action of steam. He first constructed a *piston with an elastic packing* of hemp, by which it is kept steam and air-tight as it moves along the cylinder; and, above all, availed himself of the experience of an unlucky accident to add the important process in the steam-engine of *condensation of steam by injection of cold water* directly amongst it. All these inventions of Newcomen give to the steam-engine of the present day its most important features; and if we add to these the *scoggan* or *sculking gear of Potter* by which the attendant of the engine was enabled to scog or *sculk* from his work, leaving *the engine itself,* by an ingenious complication of strings and catches to do his work, *opening and shutting its own valves,* with much greater *precision, quickness, and regularity,* than the listless attendant had ever exercised or even the very closest attention could attain; and if, further, we include the ingenious and more permanent *mechanism which* Beighton *introduced* as a substitution for the rude expedients of strings and straps; and, finally, if we include the *admirable proportions and constructions, and adaptations* of all the various parts of the engine to each other, and to the boilers and furnaces, and of these to the nature of the work to be done, as displayed in the magnificent at-

mospheric engines of the sagacious and philosophical Smeaton, we shall comprehend, in this succinct view, all that had been done for the steam-engine previously to the time of Watt.

Fig. 23.



The following is Dr Robison's description and explanation of Newcomen's engine :—

" Let A (fig. 23) represent a great boiler properly built

in a furnace. At a small height above it is a cylinder CBBC of metal, bored very truly and smoothly. The boiler communicates with this cylinder by means of the throat or steam-pipe N. The lower aperture of this pipe is shut by the plate N, which is ground very flat, so as to apply very accurately to the whole circumference of the orifice. The plate is called the regulator or steam-cock, and it turns horizontally round an axis *b a* which passes through the top of the boiler, and is nicely fitted to the socket, like the key of a cock, by grinding. The upper end of this axis is furnished with a handle *b*T.

"A piston P is suspended in this cylinder, and made air-tight by a packing of leather or soft rope, well filled with tallow; and, for greater security, a small quantity of water is kept above the piston. The piston-rod PD is suspended by a chain, which is fixed to the upper extremity F of the arched head FD of the great lever or working beam FK, which turns on the gudgeon O. There is a similar arched head EG at the other end of the beam. To its upper extremity E is fixed a chain carrying the pump-rod KL, which raises the water from the mine. The load on this end of the beam is made to exceed considerably the weight of the piston P at the other extremity.

"At some small height above the top of the cylinder is a cistern W called the injection cistern. From this descends the injection-pipe ZSR, which enters the cylinder through its bottom, and terminates in a small hole R, or sometimes in a nozzle pierced with many smaller holes diverging from a centre in all directions. This pipe has, at S, a cock called the injection-cock, fitted with a handle V.

"At the opposite side of the cylinder, a little above its bottom, there is a lateral pipe, turning upwards at the extremity, and there covered by a clack-valve *f*, called the snifting valve, which has a little dish round it to hold water for keeping it air-tight.

"There proceeds also from the bottom of the cylinder a pipe *p e g h*, (passing behind the boiler,) of which the lower end is turned upwards, and is covered with a valve *h*. This part is immersed in a cistern of water Y, called the hot well, and the pipe itself is called the eduction-pipe. Lastly, the boiler is furnished with a safety-valve called the puppet-clack, (which, for want of room, is not represented in this sketch,) in the same manner as Savary's engine. This valve is generally loaded with one or two pounds on a square inch; so that it allows the steam to escape when its elasticity is one-tenth greater than that of common air. Thus all risk of bursting the boiler is avoided, and the pressure outwards is very moderate; so also is the heat. For, by inspecting the table of vaporous elasticity, we see that the heat corresponding to 32 inches of elasticity is only about 216° of Fahrenheit's thermometer.

"These are all the essential parts of the engine, and are here drawn in the most simple form, till our knowledge of their particular offices shall show the propriety of the peculiar forms which are given to them. Let us now see how the machine is put in motion, and what is the nature of its work.

"The water in the boiler being supposed to be in a state of strong ebullition, and the steam issuing by the safety-valve, let us consider the machine in a state of rest, having both the steam-cock and injection-cock shut

The resting position or attitude of the machine must be such as appears in the sketch, the pump-rods preponderating, and the great piston being drawn up to the top of the cylinder. Now open the steam-cock by turning the handle T of the regulator. The steam from the boiler will immediately rush in, and flying all over the cylinder, will mix with the air. Much of it will be condensed by the cold surface of the cylinder and piston, and the water produced from it will trickle down the sides, and run off by the eduction-pipe. This condensation and waste of steam will continue till the whole cylinder and piston are made as hot as boiling water. When this happens, the steam will begin to open the snifting-valve *f*, and issue through the pipe; slowly at first, and very cloudy, being mixed with much air. The blast at *f* will grow stronger by degrees, and more transparent, having already carried off the greatest part of the common air which filled the cylinder. We supposed that the water was boiling briskly, so that the steam was issuing by the safety-valve which is in the top of the boiler, and through every crevice. The opening of the steam-cock puts an end to this at once, and it has sometimes happened that the cold cylinder abstracts the steam from the boiler with such astonishing rapidity, that the pressure of the atmosphere has burst up the bottom of the boiler. We may here mention an accident of which we were witnesses, which also shows the immense rapidity of the condensation. The boiler was in a frail shed at the side of the engine-house; a shoot of snow from the top of the house fell down and broke through the roof of the shed, and was scattered over the head of the boiler, which

was of an oblong or oval shape. In an instant the sides of it were squeezed together by the pressure of the atmosphere.

"When the manager of the engine perceives that not only the blast at the snifting-valve is strong and steady, but that the boiler is now fully supplied with steam of a proper strength, appearing by the renewal of the discharge at the safety-valve, he shuts the steam-cock, and opens the injection-cock S by turning its handle V. The pressure of the column of water in the injection-pipe ZS, immediately forces some water through the spout R. This coming in contact with the pure vapour which now fills the cylinder, condenses it, and thus makes a partial void, into which the more distant steam immediately expands, and by expanding collapses, (as has been already observed.) What remains in the cylinder no longer balances the atmospherical pressure on the surface of the water in the injection-cistern, and therefore the water spouts rapidly through the hole R, by the joint action of the column ZS, and the unbalanced pressure of the atmosphere; at the same time the snifting-valve *f*, and the eduction-valve *h*, are shut by the unbalanced pressure of the atmosphere. The velocity of the injection water must therefore rapidly increase, and the jet will dash (if single,) against the bottom of the piston, and be scattered through the whole capacity of the cylinder. In a very short space of time, therefore, the condensation of the steam becomes universal, and the elasticity of what remains is almost nothing. The whole pressure of the atmosphere is exerted on the upper surface of the piston, while there is hardly any on its under side. Therefore, if the load on the outer end E of the working-beam be inferior to

this pressure, it must yield to it. The piston P must descend, and the pump-piston L, must ascend, bringing along with it the water of the mine; and the motion must continue till the great piston reaches the bottom of the cylinder; for it is not like the motion which would take place in a cylinder of air rarefied to the same degree. In this last case, the impelling force would be continually diminished, because the capacity of the cylinder is diminished by the descent of the piston, and the air in it is continually becoming more dense and elastic. The piston would stop at a certain height, where the elasticity of the included air, together with the load at E, would balance the atmospherical pressure on the piston. But when the contents of the cylinder are pure vapour, and the continued stream of injected cold water keeps down its temperature to the same pitch as at the beginning, the elasticity of the remaining steam can never increase by the descent of the piston, nor exceed what corresponds to this temperature. The impelling or accelerating force therefore remains the same, and the descent of the piston will be uniformly accelerated, if there be not an increase of resistance arising from the nature of the work performed by the other end of the beam. This circumstance will come under consideration afterwards, and we need not attend to it at present. It is enough for our present purpose to see, that if the cylinder have been completely purged of common air before the steam-cock was shut, and if none have entered since, the piston will descend to the very bottom of the cylinder. And this may be frequently observed in a good steam-engine, where every part is air-tight. It sometimes happens, by the pit-pump drawing air, or some part of the communication between

the two strains giving way, that the piston comes down with such violence as to knock out the bottom of the cylinder with the blow.

"The only observation which remains to be made on the motion of the piston in descending is, that it does not begin at the instant the injection is made. The piston was kept at the top by the preponderancy of the outer end of the working-beam, and it must remain there till the difference between the elasticity of the steam below it and the pressure of the atmosphere exceed this preponderancy. There must, therefore, be a small space of time between the beginning of the condensation and the beginning of the motion. This is very small, not exceeding the third or the fourth part of a second; but it may be very distinctly observed by an attentive spectator. He will see, that the instant the injection-cock is opened, the cylinder will sensibly rise upwards a little by the pressure of the air on its bottom. Its whole weight is not nearly equal to this pressure; and instead of its being necessary to *support* it by a strong floor, we must *keep it down* by strong joists loaded by heavy walls. It is usual to frame these joints into the posts which carry the axis of the working-beam, and are therefore loaded with the whole strain of the machine. This rising of the cylinder shows the instantaneous commencement of the condensation; and it is not till *after* this has been distinctly observed, that the piston is seen to start, and begin to descend.

"When the manager sees the piston as low as he thinks proper, he shuts the injection-cock, and opens the steam-cock. The steam has been accumulating above the water in the boiler during the whole time of the piston's descent,

and is now rushing violently through the puppet clack. The moment, therefore, that the steam-cock is opened, it rushes violently into the cylinder, having an elasticity greater than that of the air. It therefore immediately blows open the snifting valve, and allows (at least) the water which had come in by the former injection, and what arose from the condensed steam, to descend by its own weight through the eduction-pipe *d e g h*, to open the valve *h*, and to run out into the hot well. And we must easily see that this water is boiling hot; for while lying in the bottom of the cylinder, it will condense steam till it acquire this temperature, and therefore cannot run down till it condenses no more. There is still a waste of steam at its first admission, in order to heat the inside of the cylinder and the injected water to the boiling temperature; but the space being small, and the whole being already very warm, this is very soon done; and when things are properly constructed, little more steam is wasted than what will warm the cylinder; for the eduction-pipe receives the injection water even during the descent of the piston, and it is therefore removed pretty much out of the way of the steam.

"This first puff of the entering steam is of great service: it drives out of the cylinder the vapour which it finds there. This is seldom pure watery vapour: all water contains a quantity of air in a state of chemical union. The union is but feeble, and a boiling heat is sufficient for disengaging the greatest part of it by increasing its elasticity. It may also be disengaged by simply removing the external pressure of the atmosphere. This is clearly seen when we expose a glass of water in an exhausted receiver. Therefore the small space below the

piston contains watery vapour mixed with all the air which had been disengaged from the water in the boiler by ebullition, and all that was separated from the injection water by the diminution of external pressure. All this is blown out of the cylinder by the first puff of steam. We may observe in this place, that waters differ exceedingly in the quantity of air which they hold in a state of solution. All spring-water contains much of it: and water newly brought up from deep mines contains a great deal more, because the solution was aided in these situations by great pressures. Such waters sparkle when poured into a glass. It is therefore of great consequence to the good performance of a steam-engine to use water containing little air, both in the boiler and in the injection cistern. The water of running brooks is preferable to all others, and the freer it is from any saline impregnation it generally contains the less air. Such engines as are so unfortunately situated that they are obliged to employ the very water which they have brought up from great depths, are found greatly inferior in their performance to others. The air collected below the piston greatly diminishes the accelerating force, and the expulsion of such a quantity requires a long-continued blast of the best steam at the beginning of every stroke. It is advisable to keep such water in a large shallow pond for a long while before using it.

"Let us now consider the state of the piston. It is evident that it will start, or begin to rise, the moment the steam-cock is opened; for at that instant the excess of atmospherical pressure, by which it was kept down in opposition to the preponderancy of the outer end of the beam, is diminished. The piston is therefore *dragged*

upwards, and it will rise even although the steam which is admitted be not so elastic as common air. Suppose the mercury in the barometer to stand at 30 inches, and that the preponderancy at the outer end of the beam is $\frac{1}{9}$th of the pressure of the air on the piston, the piston will not rise if the elasticity of the steam be not equal to $30-\frac{30}{9}$, that is, 26.7 inches nearly; but if it be just this quantity, the piston will rise as fast as this steam can be supplied through the steam-pipe, and the velocity of its ascent depends entirely on the velocity of this supply. This observation is of great importance; and it does not seem to have occurred to the mathematicians, who have paid most attention to the mechanism of the motion of this engine. In the mean time, we may clearly see that the entry of the steam depends chiefly on the counter-weight at E: for suppose there was none, steam no stronger than air would not enter the cylinder at all; and if the steam be stronger, it will enter only by the excess of its strength. Writers on the steam-engine (and even some of great reputation) familiarly speak of the steam giving the piston a push; but this is scarcely possible. During the rise of the piston the snifting valve is never observed to blow; and we have not heard any well-attested accounts of the piston-chains ever being slackened by the upward pressure of the steam, even at the very beginning of the stroke. During the rising of the piston, the steam is, (according to the common conception and manner of speaking,) *sucked in*, in the same way that air is sucked into a common syringe or pump when we draw up the piston; for in the steam-engine the piston is really drawn up by the counter-weight. But it is still more sucked in, and requires a more copious supply, for another reason.

As the piston descended only in consequence of the inside of the cylinder's being sufficiently cooled to condense the steam, this cooled surface must again be presented to the steam during the rise of the piston, and must condense the steam a second time. The piston cannot rise another inch till the part of the cylinder which the piston has already quitted has been warmed up to the boiling point, and steam must be expended in this warming. The inner surface of the cylinder is not only of the heat of boiling water while the piston rises, but is also perfectly dry; for the film of water left on it by the ascending piston must be completely evaporated, otherwise it will be condensing steam. That the quantity thus wasted is considerable, appears by the experiments of Mr Beighton. He found that five pints of water were boiled off in a minute, and produced 16 strokes of an engine whose cylinder contained 113 gallons of 282 inches each; and he thence concluded that steam was 2886 times rarer than water. But in no experiment made with scrupulous care on the expansion of boiling water does it appear that the density of steam exceeds $\frac{1}{10,000}$th of the density of water. Desaguliers says that it is above 14,000 times rarer than water. We have frequently attempted to measure the weight of steam which filled a very light vessel which held 12,600 grains of water, and found it always less than one grain; so that we have no doubt of its being much more than 10,000 times rarer than water. This being the case, we may safely suppose that the number of gallons of steam, instead of being 16 times 113, were nearly five times as much; and that only $\frac{1}{5}$ was employed in allowing the piston to rise, and the remaining $\frac{4}{5}$ths were employed to warm the cylinder. But no distinct experi-

ment shows so great an expansion of water when converted into steam at 212°. Mr Watt never found it, under the pressure of the air, more than 1800 times rarer than water.

"The moving force during the ascent of the piston must be considered as resulting chiefly, if not solely, from the preponderating weight of the pit piston-rods. The office of this is to return the steam-piston to the top of the cylinder, where it may again be pressed down by the air, and make another working stroke by raising the pump-rods. But the counter-weight at E has another service to perform in this use of the engine; namely, to return the pump pistons into their places at the bottom of their respective working barrels, in order that they also may make a working stroke. This requires force independent of the friction and inertia of the moving parts; for each piston must be pushed down through the water in the barrel, which must rise through the piston with a velocity whose proportion to the velocity of the piston is the same with that of the bulk of the piston to the bulk of the perforation through which the water rises through the piston. It is enough at present to mention this in general terms: we shall consider it more particularly afterwards, when we come to calculate the performance of the engine, and to deduce from our acquired knowledge, maxims of construction and improvement.

"From this general consideration of the ascent of the piston, we may see that that motion differs greatly from the descent. It can hardly be supposed to accelerate, even if the steam in the cylinder were in a moment annihilated. For the resistance to the descent of the piston is the same with the weight of the column of water,

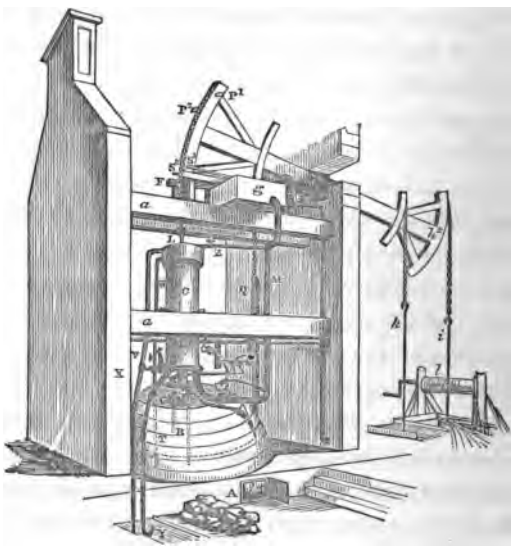
which would cause it to flow through the box of the pump-piston with the velocity with which it really rises through it, and must therefore increase as the square of that velocity increases; that is, as the square of the velocity of the piston increases. Independent of friction, therefore, the velocity of descent through the water must soon become a maximum, and the motion become uniform. We shall see by and by, that in such a pump as is generally used, this will happen in less than the 10th part of a second. The friction of the pump will diminish this velocity a little, and retard the time of its attaining uniformity. But, on the other hand, the supply of steam which is necessary for this motion, being susceptible of no acceleration from its previous motion, and depending entirely on the briskness of the ebullition, an almost instantaneous stop is put to acceleration.

"Accordingly, any person who observes with attention the working of a steam-engine, will see that the rise of the piston and descent of the piston-rods is extremely uniform, whereas the working stroke is very sensibly accelerated. Before quitting this part of the subject, and lest it should afterwards escape our recollection, we may observe, that the counter-weight is different during the two motions of the pump-rods. While the machine is making a working stroke, it is lifting not only the column of water in the pump, but the absolute weight of the pistons and piston-rods also; but while the pump-rods are descending, there is a diminution of the counter-weight by the whole weight lost by the immersion of the rod in water. The wooden rods which are generally used, soaked in water, and joined by iron straps, are heavier, and but a little heavier, than water; and they

are generally about one-third of the bulk of the water in the pumps.

"These two motions complete the period of the operation; and the whole may be repeated by shutting the steam-cock and opening the injection-cock whenever the piston has attained the proper height. We have been very minute in our attention to the different circumstances, that the reader may have a distinct notion of the state of the moving forces in every period of the operation. It is by no means sufficient that we know in general that the injection of cold water makes a void

Fig. 24.

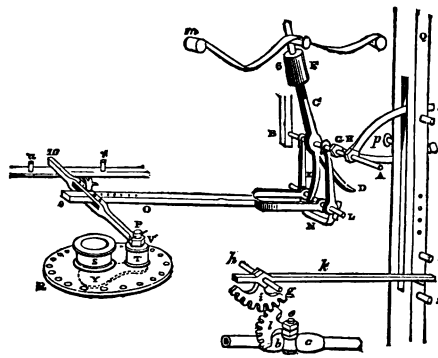


which allows the air to press down the piston, and that the re-admission of the steam allows the piston to rise again. This lumping and slovenly way of viewing it has

long prevented even the philosopher from seeing the defects of the construction, and the methods of removing them."

It was in 1718, as already mentioned, that Mr Henry Beighton improved the steam-engine of Newcomen, by a simple and effective arrangement of minor details, which left so little to be desired for the practical use of the engine in pumping water, that for more than half a century it remained in general use, without any change of form or arrangement. The following excellent diagrams and quaint descriptions are from the pen of Desaguliers, who had made himself very well acquainted with the subject as it existed in his time.

Fig. 25.

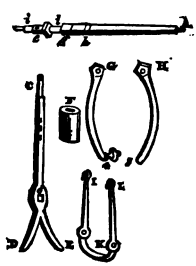


"The working perpendicular beam is in figure 24 represented in the whole, with all its contrivances for opening and shutting the regulator and injection-cock, and marked QQ.

"Between two perpendicular pieces of wood on each side of P, there is a square iron axis, which has upon it four iron pieces subservient to the turning of the regu-

lator, by shooting forward and drawing back the fork fastened to the hand of the regulator; it is marked L N O in fig. 25, and represented separately in fig. 27. There is a slit in the perpendicular working-beam contrived in such manner that its pins work on the fore part, middle, and back part, to raise and depress the levers 5, 4, (fig. 25,) that move the iron axle-tree above-mentioned as far about its centre as is necessary. But the reader will conceive the thing better by a view of the pieces in figs. 26 to 29, and then be enabled fully to understand the same things in fig. 25.

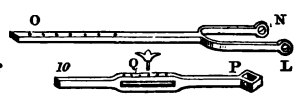
Fig. 26.



"A, Figure 26, represents the iron axle-tree already mentioned, and marked by the letters A B in figure 25. There is a piece *c e* D E, called the Y, from its representing that letter by its two shanks, only hanging down in an inverted order, with a weight F to be slipped on upon its upper part, where it is made fast, higher or lower, as is convenient, with a key or wedge. This Y being slipped on over the end of the iron axle is made fast by driving in a key after it at *e*: then there is a sort of a stirrup, I K I, with a long pin to be fixed occasionally into the holes on each side of K: this, by its hooks I I, is hung upon the axle at *i i*, then a spanner or handle G 4 is driven on upon the axle from the other end, so as to come and be fast at *g* at right angles to the Y: then a shorter lever or spanner at half right angles to this, (that is, between the long shank of the Y and G 4,) is forced on to *h*, upon the axle, where it is made fast. All these pieces, as they are fixed together on the axle

may be seen at figure 25; where you may observe, that when the working-beam goes up, by a pulley held in its middle by a pin, it lifts up the spanner H 5, which turns the axle so far as to throw the Y with its weight F from C to 6, in which direction, after passing the perpendicular, it would continue to move towards Q, if it was not stopped by a strap of leather fixed to its top and made fast at the points *m n*, in such manner as to allow the Y to vibrate about a quarter of a circle, in falling forwards and backwards, after it has passed the perpendicular.

Fig. 27.

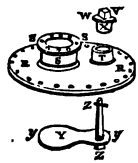


"Figure 27 represents the horizontal fork L N O to be joined, at its end O, to the spanner or handle of the regulator P Q 10, there being several holes in these pieces, that any part of the end O may be kept in any part of the slit in the spanner, as may be requisite for the better motion of the two pieces. This may be seen in figure 25, where the other end of the fork is fastened to the bottom of the stirrup at K N L, by the long horizontal pin L, so that the fork may continue horizontal, as it is shot forward, and drawn back by the strokes that K and D, the shanks of the Y, make alternately on the fore part or back part of the pin L, in order to push forward, or draw back the spanner P 10, to shut or open the regulator in the manner that shall be further explained. We will only take notice now, that there is an horizontal piece *u l*, so placed, that the end 10 of the spanner may bear upon it, and be supported, as it slides backward and forward.

"Before we proceed, it will not be improper to give a full description of the regulator. See fig. 28.

"A cock of four inches water-way, big enough to let the steam out of the boiler into the cylinder, would have so much friction, if made tight, as to require a great force to turn it, especially as it must open and shut 32 times in a minute; therefore the regulator has been contrived instead of it. The brass plate R, which you see here at RR in the middle of the top of the boiler, is cast with the pipe S S S of four inches' bore, and worked smooth at its hole under the plate, that it may be closely stopped by another smooth plate *y* Y *y* applied under it, (where the pressure of the steam will hold it the closer when shut.) There is also, in the plate RR, a short pipe or conic hole T, smallest downwards, to receive the piece V W X, which being ground into it can move round without letting air or steam pass by. There is a square shank ZZ, which is put through this last piece when it is let down into its hole, and pinned tight to it at the upper Z. Then the spanner of the regulator being put on, and made fast at V and W, as may be plainly seen in fig. 25, where the whole regulator is put together. This regulator opens very quick, and ten times easier than a cock of the same bore: and to help the whole, the weight F of the Y, when it has passed the perpendicular, falls with a good force, which makes the shank under it give a smart stroke, either within the fork or without, to drive the fork, and draw the handle of the regulator contrary to the way that the weight is falling: the weight causing the regulator to be shut when it tumbles towards it, and be open when it tumbles from it.

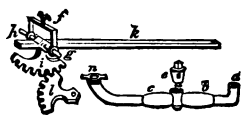
Fig. 28.



"When the regulator is shut, the next thing is to open the injection-cock to make the vacuum, and immediately

to shut it when the piston begins to come down, (for the vacuum is made in a second of time.) *n* (fig. 29,) represents the adjutage of the injecting pipe within the cylinder; *a b* part of the pipe coming from the injecting-cistern, *c b* the cock, and *e* the key of the cock, that has a narrow, long, upright hole instead of a round one, that it may be the sooner opened. Upon the top of this key is fastened on a quarter of a wheel with teeth *l*, to be turned by another quarter of a wheel *i* hanging down from the axis *h g*, which is moved by the lever *h k*, commonly called the F. Examine fig. 25, where they are working together, and you may see how the perpendicular beam moves them by its pins.

Fig. 29.



" The present situation of the machine, as now represented by the 24th figure, is as follows. The regulator is open, as appears by its plate TY being removed from under the communication or throat-pipe S, that goes into the cylinder. The piston is now up about the place CW, at top of the cylinder in figure 24; consequently the great beam, and the working perpendicular beam are now almost at their utmost height, and the pulley in the slit of the working beam has so far raised the spanner H 5, that the weight or head of the Y is brought so far from under *n*, as to be past the perpendicular over the axle; and being ready to fall over towards *m*, it will with a smart blow of its shank K, strike the pin L, and drawing the fork ON horizontally towards the working beam, will draw the end 10 of the handle of the regulator toward *l*, and thereby shut it, by slipping the plate Y under the pipe S. The engine in figure 25 is in this very con-

dition; but in figure 24 the blow is already struck, and the communication cut off; as may be known by observing that the weight at the head of the Y is got as far as the strap will let it go.

"The moment after the regulator is shut, the beam not immediately losing its motion upwards, the pin *s* on its outside lifts up the end I of the F, *h k i*, and opens the injection-cock; and the jet immediately making a vacuum, the beam begins to descend, and the pin *r* (which you may put higher or lower) depressing the F, shuts the injection-cock: then the beam continuing to descend, the pulley *p*, pressing on the handle G 4, throws back the Y, whose shank D throws forward the fork, and opens the regulator to let in fresh steam, in the manner already described; which steam is shut off, by shutting the regulator till the cock for injection of cold water is again opened,"

Newcomen, Potter, and Beighton, had thus rendered the atmospheric steam-engine an independent self-acting mechanical power of so great perfection in its principle of action, and its minor details, as to be very generally introduced as a substitute for the power of animals in draining mines and collieries, and to confer very great advantages in those important and primary sources of national industry and wealth. The saving of money resulting from this change was so great as to be continually opening up new avenues of mining enterprise; and, by the rapid progress of that enterprise, the capabilities of the engine were soon put to the severest trial. The cylinders, which had been originally of twelve and sixteen inches diameter, were increased to twenty, thirty, and forty inches, and at last even fifty and sixty inches

in diameter. Along with this dimension, the other parts required to be increased in a still higher proportion; and at last the structures became so gigantic as to demand an amount of science and practical skill which in that period of engineering science was rarely to be found. The man suited to the emergency at last arose in the father of civil engineering, the justly celebrated Smeaton, who brought to bear on this subject endowments and accomplishments seldom united; fertile ingenuity, accurate philosophic conceptions, and sound practical sagacity. He conferred upon the atmospheric steam-engine all the extent and variety of application of which it was capable, and all the perfection of proportion and execution which the state of the mechanical arts would permit.

The manner in which Smeaton proceeded to the improvement of the atmospheric engine was one which is worthy of all praise and imitation. Unlike too many of the engineering experiments of the present day, as well as of past times, his were made at his own expense, not at the expense of his employers, and on a scale sufficiently large to ensure sound results, without being on that scale which should entail unwarrantable expense. Having encountered some anomalous results in the earlier parts of his experience with atmospheric engines, he resolved, as he says, "if possible to make himself master of the subject, and immediately began to build a small fire-engine, which could easily be converted into different shapes for experiments." This experimental engine was set to work at Austhorpe in 1769. With it he made a very great number of valuable experiments, so as to ascertain the length and velocity of stroke and return, the quantity and manner of injection, the proportion of load,

the dimensions of cylinder, and the materials of construction, which were required to produce the maximum of useful effect from a given amount of fuel. Mr Farey has given us the dimensions of this model, and the results of the experiments of Smeaton as they are here set down. The cylinder was 9.9 inches in diameter, and had a working-stroke of 3 feet. The piston made $17\frac{1}{2}$ strokes per minute, passing over 105 feet per minute, going and returning, or over 52.5 effective feet per minute; its load per square inch was 7.89 lbs., its total load 607 lbs. The quantity of coals consumed was 55 lbs. per hour. The work done was equivalent to 31,867 lbs. raised 1 foot high per minute = 0.966 horse power. The work of one bushel or 84 lbs. of coal was equal to 2,919,017 lbs. raised 1 foot high. The weight of water evaporated by 1 lb. of coal was 6.14 lbs., and the quantity of cold water injected was 10.66 the evaporated water.

When the engine made its stroke the mercury was raised to 23.2 inches.

Mr Smeaton found that this engine produced its maximum effect both as regards quantity and economy when carrying a load of 7.81 lbs. on the inch. When the load was reduced to 6.6 lbs. the power of the engine was lessened in the proportion of 100 to 94. When the load was reduced to 5.5 lbs. the power of the engine was still further lessened in the proportion of 94 to 82. In these two cases the work produced by 1 lb. of coals was reduced in the proportion of 100 to 94, and 94 to 80.

When, on the other hand, the load was increased from 7.8 lbs. to 8.8 lbs. per inch, the work done was only increased from 100 to 107. When the load was still further increased to 9.1 lbs. the work was diminished from 100

to 96. But in both these the economy of fuel was diminished in a higher proportion, the work produced by each lb. of coals being reduced in the proportions 100 to 97, and 97 to 93.

Mr Smeaton also found, from the same engine, the best kinds of fuel and the best modes of burning it. Round coals were found superior to small coal in the proportion of 100 to 80 nearly. Coke produced $\frac{5}{6}$ of the effect of an equal weight of the same coal from which the coke was made, and 66 lbs. of coke were obtained from 100 lbs. of coal. Ash-wood used as fuel was found inferior to common Yorkshire coals in the proportion of 42 to 100. The performance of the kind of Newcastle coals called Team Top, was found superior to the common Yorkshire or Halton coal, in the ratio of 120 to 100. Cannel coal from Wakefield in Yorkshire, was superior to Halton in the ratio 133 to 100. Middleton-wood coals, and Welsh coals, were superior to Halton, as 110 to 100; and Berwick-moor coals were inferior to Halton, in the ratio 86 to 100.

In consequence of this admirable method of procedure, Mr Smeaton improved the proportions and structure of the atmospheric engine, and very soon produced machines which excelled in their dimensions and efficiency every thing which had preceded them. In 1772 he erected an engine at Long Benton colliery, near Newcastle, which he ever afterwards considered as his standard. The following are its principal dimensions and performance: Diameter of the cylinder, 52 inches—7 feet stroke, 12 strokes per minute, being 84 feet useful motion per minute, and 168 feet total motion per minute. Load of water = 7.1 tons. Load per square inch =

7½ lbs. Consumption of coals, 17.63 lbs. per horse power per hour. Work of one bushel or 84 lbs. of coals = 9.45 millions of lbs. one foot high. The total power of engine was about 40½ horse-power, and for every horse-power the boiler had 52 cubic feet of total space, 27.75 cubic feet of steam room, and 6.25 square feet of horizontal surface of water. The furnace had, for every horse power, 3.5 square feet of fire surface, 7.83 square feet of flue surface, and .867 square foot of fire grate. The total steam produced per minute was about 62.95 feet per horse power; of this 30.58 feet were used in moving the piston, 8.92 feet wasted to fill the extra space in the cylinder, and 23.45 condensed on the surface of the cylinder.

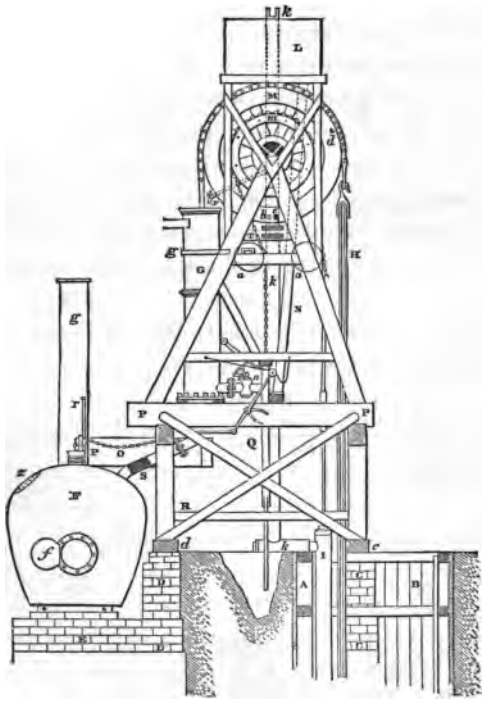
Mr Farey has given an excellent description and investigation of this engine, with two plates taken with his wonted fidelity and beauty, from the original drawings.

Mr Smeaton also constructed a portable fire-engine, for the purpose of being used to draw water from temporary excavations, shafts, quarries, &c., so framed as to require no erection of a building, and to be easily removed from place to place. The fire is wholly within the boiler. The framing of the engine is constructed of timber, trussed and arranged in such a manner as to contain within it every kind of strain whatever which the force of the machine and the resistance may produce. The details of this engine are given in his reports, from which we extract the following figures and descriptions:

Fig. 30 contains a side view of the engine and boiler. AB is the pit or shaft. CC is the upright of the foundation walls on each side of the pit, for supporting the ground sill *c* across the pit, upon which one side of the

engine-frame is raised. DD is the foundation wall for supporting the groundsill *d*, upon which the other side is raised; E the foundation wall for supporting the boiler,

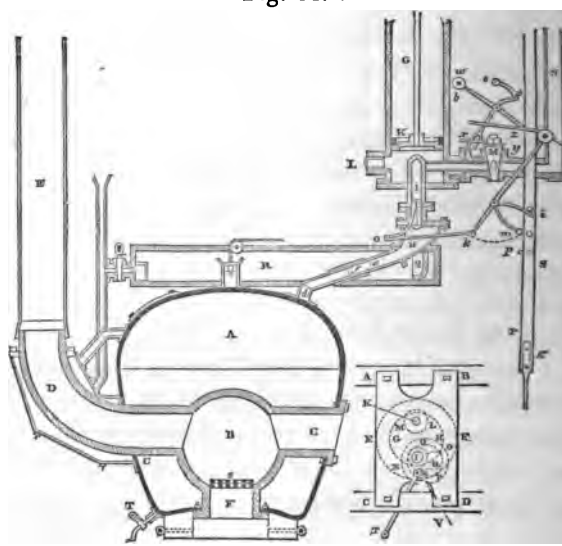
Fig. 30.



and forming the ash-hole. F is the boiler, *f* the fire-door, *g* the chimney, S the steam-pipe, p the puppet-clack, *r* the feeding-pipe funnel, *z* the man-hole, G the cylinder, H the main pump spear, I the jackhead-pump, by the continuation whereof, *k k k*, the water, is conveyed into L, the injecon-cistern. M is a wheel serving instead of the great

beam, *m* a rim of a smaller diameter, attached to the former, for working the jackhead-pump I, and plugframe Q. *a a* are pulleys to bring their chains into a convenient place for working. The wheel is stopped at the end of its intended stroke, which is to be $6\frac{1}{2}$ feet stop and stop, by means of the two iron fids *b b*, which, reaching out on each side of the great rim, stop against two strong iron pins *e e*, which are fixed into a cross beam S, framed into the piece T, and the whole firmly bolted together, as shown in the design. N is the injection-pipe, *n* the injection-cock, and *x* the piston water-cock. O is the hot well. R is a stage for the person to stand upon who hands the engine. PP are the two main beams or sleepers, upon which the cylinder is seated upon its bottom and bolted down. The whole is kept from springing or flying off by an iron strap.

Fig. 31.



The waste water pipes are omitted to prevent confusion. Fig. 31 shows a section of the boiler, cylinder, and pipes, with the working-gear, to a larger scale, the whole being divested of the framing in order to render every thing more distinct.

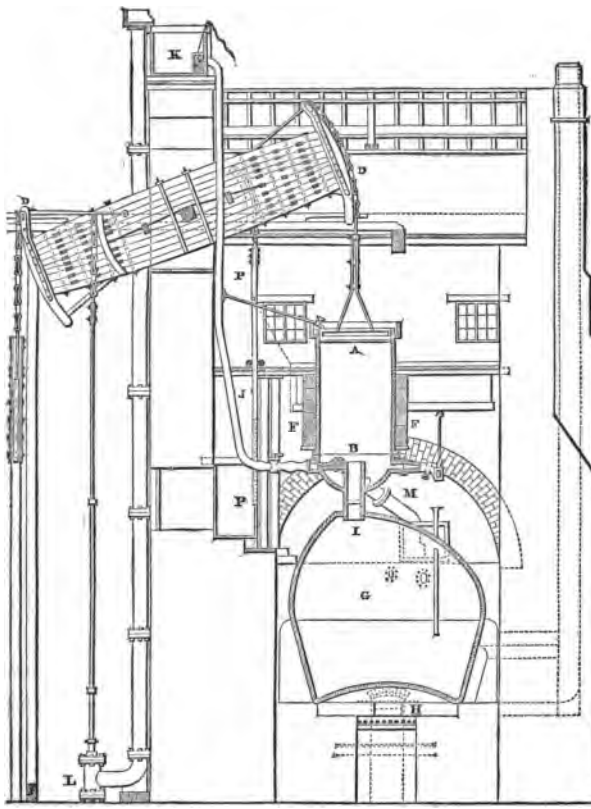
The boiler is supposed to be turned one quarter round from its true position, in order that the most material parts may be brought into one view. It is also to be noted, that every vessel or pipe is supposed to be cut right through the middle, in order to show the contents, and that the section is not confined to any particular plane; but, for the more perfect explaining of the principal figure, it will be best to begin with the little plan at the right-hand corner of the figure. ABCD is a plan of the cylinder bottom, bolted down upon the two main beams AB and CD; the dotted circle EF shows the extremity of the bottom flanch of the cylinder, and the circle GH, the diameter of the cylinder within; the hole I answers the steam-pipe and regulator, and the hole K the eduction or sinking-pipe, and the circle LM its flanch; the circle NO shows the size and position of the regulator-plate, and the dotted circle PQ the size of the receiver in which the sliding-valve of the regulator R works, and in this position is open; ST is the lever by which it is worked, and when that is brought forward into the position SV, then the valve covers the aperture of the regulator. In the principal figure, A is the boiler, and B the fire-place, which is of cast iron and of a spherical form, and placed in the interior of the boiler. The coals are introduced by the large pipe C, and the smoke is conducted by the curved pipe D into the funnel or chimney E The ashes fall through the grate S and the wide pipe

F, into the ash-holes below. The other appendages of the boiler, are a cock for emptying it, marked T, two gauge-cocks for ascertaining the height of the water, the puppet-clack or safety-valve, loaded with a sufficient weight, and having a string attached to it, so that the attendant on the engine can raise it when necessary to allow the steam to escape. The boiler has also a man-hole, which is better seen at Z in fig. 30. The curved smoke-pipe D is surrounded by a copper casing, into which the water for feeding the boiler flows from the hot well, so as to be highly heated before being admitted into the boiler. The other parts of the engine shown in the figure are, G the cylinder, into which the steam from the boiler flows through the pipes *d e* H I, which are jointed at *f* for the readier taking asunder, K the piston, G the piston-rod, H the receiver for the steam, containing the regulator-valve, I the steam-pipe, L the snifting-clack, M the injection-cock, N the injection-pipe, P *p y* the plug-frame, *i m* arms of the tumbler on which the plugs act, *k o* a rod connecting the end of the tumbler with the handle of the regulator, *w b x z* the faller or F lever, with its detent or catch at *o*.

But the most magnificent of Smeaton's works in this department of his profession is his great Chasewater engine, of which the details are given in his Reports. This engine was of 150 horses' power, turning out 880 hogsheads of water per hour, by the heat of 16½ bushels of coal. We have given a cut of this engine, Fig. 32; and we recommend the engineer to consult the original in Smeaton's Reports, as it is full of ingenious contrivance and judicious arrangement. The cylinder A B is 72 inches in diameter, the stroke 10 feet 6 inches. The great

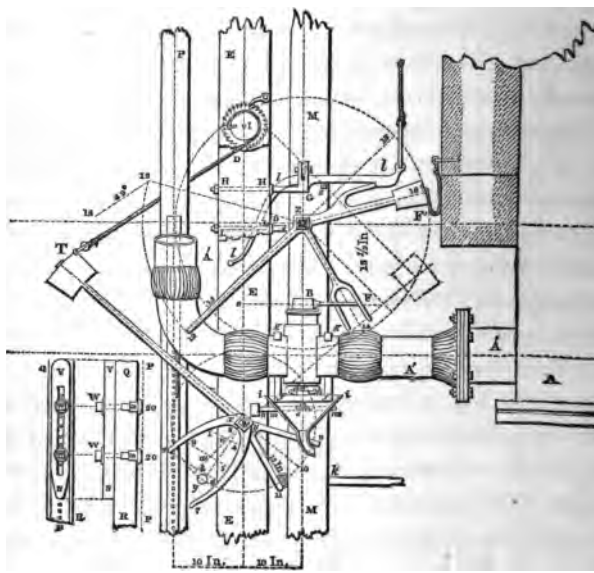
beam of the engine, DD, consists of twenty large balks of timber, the four nearest the centre being each a foot square, and the whole firmly joggled together with heart of oak, and bolted with iron, forming a very elegant but ponderous beam. The cylinder beams FF, upon which the

Fig 32.



cylinder rests, and which are kept in their place by being entered into the side walls of the house, are joggled and framed together in a similar manner to the great lever. G is the boiler, H the furnace, I B the steam-pipe, J the injection-pipe, K the cistern for the injection water, fed by a pump L, which is wrought by the great lever of the engine, M the waste-pipe for the condensed steam, N the spear or pump-rod of the great draining-pump wrought by the engine, P P the plug-tree suspended from the main beam carrying plugs, which in its upward and downward progress act on the levers which open and shut the regulator and injection-cocks. The date of this engine is 1775. The working gear of the engine is very

Fig. 33.



simple and good. It is represented on a larger scale in the cut, fig. 33.

A is the lower corner of the cylinder, A A′ A′ the injection-pipe, B the injection-cock, B F its handle or spanner passing between the forks of the bent lever E Z F F′, called the F lever, by which the cock is opened and shut. The tail Z 12 of this F lever is, by the downward motion of the plug-tree P, forced from the position shown by the dotted line Z 18, into the position in which it is seen in the drawing, and it is there retained by the catch *l l l*. While the lever is in this position the injection-cock is shut, the steam from the boiler is flowing into the cylinder, and the piston is rising. When the piston has nearly reached the top of its course, an apparatus attached to the plug-frame P, draws up the catch *l l l*, and releases the F lever, which is forced into the position 18 Z, by the bob or weight 16, carried by its end F′, and the consequent movement of its fork F opens the injection-cock; T *x* 11, 9, is the Y lever or tumbler, which acts upon the stirrup rod *k* attached to the spanner of the regulator, as in Beighton's gear, figs. 25, 27. The range of the tumbler's motion on each side of the perpendicular is regulated by its check-cord T I, which is passed round a roller I, furnished with a paul and ratchet, so that its length may be adjusted. The tumbler is moved by pins in the plug-frame P, acting upon its bent arms *x* 3, *x* 7.

In the left-hand corner at the bottom of the figure is seen a representation of a slider, which may be fixed upon the plug-tree instead of the pins, to work the lever. There is both a side and a front view of the slider. Q R shows a part of the plug-tree, N V the slider, and W 20 W 20 two screws for retaining the slider in its place. By this

means the working-stroke may be adjusted much more surely than by the pins or plugs.

The working of the injection-cock by the forked end of the F lever was found to be defective, and Mr Smeaton, in the engines which he afterwards constructed, fixed a toothed sector on the end of the lever, which was made to act upon a toothed wheel, carried by the axis of the injection-cock, somewhat in the manner of the parts of Beighton's gear represented in figs. 25, 29.

3. *The Era of Watt.*

Before the time of JAMES WATT, the steam or atmospheric engine was a more costly power than horses, except where fuel was extremely cheap. At the mouth of a coal-pit almost any sort of steam-engine or fire-engine is better than horses, because it consumes the produce, and often the refuse of the pit, and is valuable for the purpose of volatilising the mass of small coals which would otherwise lumber the mouth of the pit. The worst sort of engine would raise more coal in twelve minutes than it would consume in twelve hours. In such circumstances, almost any fire-engine is cheaper than the labour of horses, and the more voracious of fuel the more economical of labour. We find that the rudest, most antiquated, worst made and worst tended engines in the world, are the engines of Durham coal-fields and around Newcastle, where there are more bad engines than in all the rest of the world. The reason is obvious; the only constant expense attending the use of these engines is the labour of shovelling in coals. The atmospheric engine, even after it had received all the improvements of three quarters of a century, and attained in the hands of Smeaton all the

perfection of which it was capable, still continued an extravagant consumer of coals. Watt was the man who turned the scale of expense so as to give a great preponderance in favour of the fire-engine. In his hands it ceased to be an *atmospheric engine*, and became wholly a *steam-engine*, capable of being employed in an immense variety of applications, on a much larger scale, and at much less expense than the power of horses, wherever the prices of fuel and of fodder were not in greater disparity than in this country.

We have seen that hitherto the fire-engine, even in Smeaton's hands, was an engine that wasted a large quantity of fuel and of steam in doing what was useless, namely, heating the cylinder, which was cooled alternately in each stroke by the cold water injected into it. In Long Benton colliery engine, out of sixty-three cubic feet of steam thirty-two feet were thus wasted, and the remaining thirty-one feet alone performed useful work. There remained, therefore, one-half of the power of the steam and expense of the fuel to be saved by future improvements, provided the useless heating and cooling of the cylinder could be superseded. The vacuum formed below the cylinder was also far from being perfect. Watt found the atmospheric fire-engine in the hands of Smeaton, produced from it the pure steam-engine, and left it to us in its present state of high improvement. This portion of the history of the steam-engine was contributed as a commentary upon the original article of the *Encyclopædia Britannica*, by the person of all others best qualified to do it justice, Watt himself. For the purpose of further illustration, we have added some figures, as well as some remarks.

"My attention was first directed in the year 1759 to the subject of steam-engines by the late Dr. Robison, himself then a student in the University of Glasgow, and nearly of my own age. He at that time threw out an idea of applying the power of the steam-engine to the moving of wheel carriages, and to other purposes; but the scheme was not matured, and was soon abandoned on his going abroad.

Fig. 34.

"About the year 1761 or 1762, I tried some experiments on the force of steam, in a Papin's digester, and formed a species of steam-engine by fixing upon it a syringe one-third of an inch in diameter, with a solid piston, and furnished also with a cock to admit the steam from the digester, or shut it off at pleasure, as well as to open a communication from the inside of the syringe to the open air, by which the steam contained in the syringe might escape. When the communication between the digester and syringe was opened, the steam entered the syringe, and by its action upon the piston raised a considerable weight (fifteen lbs.) with which it was loaded. When this was raised as high as was thought proper, the communication with the digester was shut, and that with the atmosphere opened; the steam then made its escape, and the weight descended. The operations were repeated, and though in this experiment the cock was turned by hand, it was easy to see how it could be done by the machine itself, and to make it work with perfect regularity But I soon relinquished the idea of constructing an engine upon this principle, from being sensible

it would be liable to some of the objections against Savary's engine, viz. the danger of bursting the boiler, and the difficulty of making the joints tight, and also that a great part of the power of the steam would be lost, because no vacuum was formed to assist the descent of the piston.

"The attention necessary to the avocations of business prevented me from then prosecuting the subject further; but in the winter of 1763-4, having occasion to repair a model of Newcomen's engine belonging to the Natural Philosophy Class of the University of Glasgow, my mind was again directed to it. At that period, my knowledge was derived principally from Desaguliers, and partly from Belidor. I set about repairing it as a mere mechanician, and when that was done and it was set to work, I was surprised to find that its boiler could not supply it with steam, though apparently quite large enough; (the cylinder of the model being two inches in diameter, and six inches stroke, and the boiler about nine inches diameter.) By blowing the fire it was made to take a few strokes; but required an enormous quantity of injection water, though it was very lightly loaded by the column of water in the pump. It soon occurred to me, that this was caused by the little cylinder exposing a greater surface to condense the steam, than the cylinders of larger engines did, in proportion to their respective contents. It was found that by shortening the column of water in the pump, the boiler could supply the cylinder with steam, and that the engine would work regularly with a moderate quantity of injection. It now appeared that the cylinder of the model, being of brass, would conduct heat much better than the cast-iron cylinders of larger

engines, (generally covered on the inside with a stony crust,) and that considerable advantage could be gained by making the cylinders of some substance that would receive and give out heat slowly. Of these, wood seemed to be the most likely, provided it should prove sufficiently durable. A small engine was therefore constructed, with a cylinder six inches diameter and twelve inches stroke, made of wood, soaked in linseed oil, and baked to dryness. With this engine many experiments were made; but it was soon found that the wooden cylinder was not likely to prove durable, and that the steam condensed in filling it still exceeded the proportion of that required for large engines according to the statements of Desaguliers. It was also found, that all attempts to produce a better exhaustion by throwing in more injection, caused a disproportionate waste of steam. On reflection, the cause of this seemed to be the boiling of water in vacuo at low heats, a discovery lately made by Dr Cullen and some other philosophers, (below 100, as I was then informed,) and consequently, at greater heats, the water in the cylinder would produce a steam which would, in part, resist the pressure of the atmosphere.

"By experiments which I then tried upon the heats at which water boils under several pressures greater than that of the atmosphere, it appeared that when the heats proceeded in an arithmetical, the elasticities proceeded in some geometrical ratio; and by laying down a curve from my data, I ascertained the particular one near enough for my purpose. It also appeared that any approach to a vacuum could only be obtained by throwing in large quantities of injection, which would cool the cylinder so much as to require quantities of steam to heat

it again, out of proportion to the power gained by the more perfect vacuum; and that the old engineers had acted wisely in contenting themselves with loading the engine with only six or seven pounds on each square inch of the area of the piston. It being evident that there was a great error in Dr Desaguliers' calculations of Mr Beighton's experiments on the bulk of steam, a Florence flask, capable of containing about a pound of water, had about one ounce of distilled water put into it; a glass tube was fitted into its mouth, and the joining made tight by lapping that part of the tube with packthread covered with glaziers' putty. When the flask was set upright, the tube reached down near to the surface of the water, and in that position the whole was placed in a tin reflecting oven before a fire, until the water was wholly evaporated, which happened in about an hour, and might have been done sooner, had I not wished the heat not much to exceed that of boiling water. As the air in the flask was heavier than the steam, the latter ascended to the top, and expelled the air through the tube. When the water was all evaporated, the oven and flask were removed from the fire, and a blast of cold air was directed against one side of the flask, to collect the condensed steam in one place. When all was cold, the tube was removed, the flask and its contents were weighed with care; and the flask being made hot, it was dried by blowing into it by bellows, and when weighed again, was found to have lost rather more than four grains, estimated at four and a third grains. When the flask was filled with water, it was found to contain about seventeen and one-eighth ounces avoirdupois of that fluid, which gave about one thousand eight hundred for the expansion

of water converted into steam of the heat of boiling water.

"This experiment was repeated with nearly the same result; and in order to ascertain whether the flask had been wholly filled with steam, a similar quantity of water was, for the third time, evaporated; and, while the flask was still cold, it was placed inverted, with its mouth (contracted by the tube) immersed in a vessel of water, which it sucked in as it cooled, until in the temperature of the atmosphere it was filled to within half an ounce measure of water.

"In repetitions of this experiment at a later date, I simplified the apparatus by omitting the tube, and laying the flask upon its side in the oven, partly closing its mouth by a cork, having a notch on one side, and otherwise proceeding as has been mentioned.

"I do not consider these experiments as extremely accurate; the only scale-beam of a proper size which I had then at my command not being very sensible, and the bulk of the steam being liable to be influenced by the heat to which it was exposed, which, in the way described, is not easily regulated or ascertained; but, from my experience in actual practice, I esteem the expansion to be rather more than I have computed.

"A boiler was constructed, which showed by inspection the quantity of water evaporated in any given time, and thereby ascertained the quantity of steam used in every stroke by the engine, which I found to be several times the full of the cylinder. Astonished at the quantity of water required for the injection, and the great heat it had acquired from the small quantity of water in the form of steam which had been used in filling the

cylinder, and thinking I had made some mistake, the following experiment was tried:—A glass tube was bent at right angles, one end was inserted horizontally into the spout of a tea-kettle, and the other part was immersed perpendicularly in well water contained in a cylindric glass vessel, and steam was made to pass through it until it ceased to be condensed, and the water in the glass vessel was become nearly boiling hot. The water in the glass vessel was then found to have gained an addition of about one-sixth part from the condensed steam. Consequently, water converted into steam can heat about six times its own weight of well water to 212°, or till it can condense no more steam. Being struck with this remarkable fact, and not understanding the reason of it, I mentioned it to my friend Dr Black, who then explained to me his doctrine of latent heat, which he had taught for some time before this period, (summer 1764;) but having myself been occupied with the pursuits of business, if I had heard of it, I had not attended to it, when I thus stumbled upon one of the material facts by which that beautiful theory is supported.

"On reflecting further, I perceived that, in order to make the best use of steam, it was necessary, first, that the cylinder should be maintained always as hot as the steam which entered it; and, secondly, that when the steam was condensed, the water of which it was composed, and the injection itself, should be cooled down to 100°, or lower, where that was possible. The means of accomplishing these points did not immediately present themselves; but *early in* 1765 *it occurred to me, that if a communication were opened between a cylinder containing steam, and another vessel which was exhausted of air and*

other fluids, the steam, as an elastic fluid, would immediately rush into the empty vessel, and continue so to do until it had established an equilibrium; and if that vessel were kept very cool by an injection, or otherwise, more steam would continue to enter, until the whole was condensed. But both the vessels being exhausted, or nearly so, how was the injection-water, the air which would enter with it, and the condensed steam, to be got out? This I proposed, in my own mind, to perform in two ways. One was by adapting to the second vessel a pipe reaching downwards more than thirty-four feet, by which the water would descend, (a column of that length overbalancing the atmosphere,) and by *extracting the air by means of a pump.*

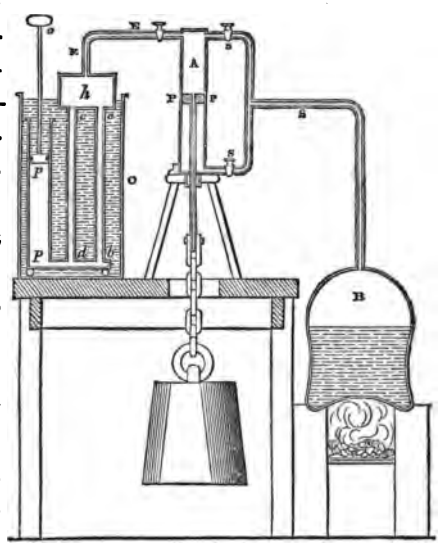
"The second method was *by employing a pump, or pumps, to extract both the air and the water,* which would be applicable in all places, and essential in those cases where there was no well or pit.

"This latter method was the one I then preferred, and is the only one I afterwards continued to use.

"In Newcomen's engine, the piston is kept tight by water, which could not be applicable in this new method; as, if any of it entered into a partially exhausted and hot cylinder, it would boil and prevent the production of a vacuum, and would also cool the cylinder by its evaporation during the descent of the piston. I proposed to remedy this defect by *employing wax, tallow, or other grease, to lubricate and keep the piston tight.* It next occurred to me that the mouth of the cylinder being open, the air which entered to act on the piston would cool the cylinder, and condense some steam on again filling it; I therefore proposed *to put an air-tight cover upon*

the cylinder, with a hole and stuffing-box for the piston-rod to slide through, and to admit steam above the piston to act upon it instead of the atmosphere. There still remained another source of the destruction of steam, the cooling of the cylinder by the external air, which would produce an internal condensation whenever steam entered it, and which would be repeated every stroke; this I proposed to remedy by *an external cylinder containing steam, surrounded by another of wood, or of some other substance which would conduct heat slowly.*

Fig. 35.



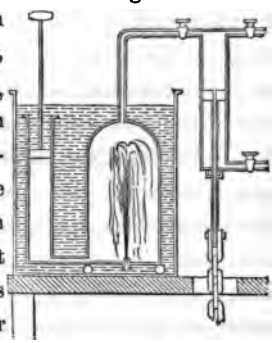
"When once the idea of the *separate condensation* was started, all these improvements followed as corollaries in quick succession, so that in the course of one or two days, the invention was thus far complete in my mind, and I immediately set about an experiment to verify it practically. I took a large brass syringe A, one and three-fourth inches diameter, and ten inches long, made a cover and bottom to it of tin-plate, with a pipe S to convey steam to both ends of the cylinder from the boiler;

another pipe E to convey steam from the upper end to the condenser, (for, to save apparatus, I inverted the cylinder.) I drilled a hole longitudinally through the axis of the stem of P the piston, and fixed a valve at its lower end, to permit the water which was produced by the condensed steam, on first filling the cylinder, to issue. The condenser used upon this occasion consisted of two pipes *a b*, *c d*, of thin tin-plate, ten or twelve inches long, and about one-sixth inch diameter, standing perpendicular, and communicating at top with a short horizontal pipe *h* of large diameter, having an aperture on its upper side which was shut by a valve opening upwards. These pipes were joined at bottom to another perpendicular pipe *p* of about an inch diameter, which served for the air and water pump; and both the condensing pipes and the air-pump were placed in a small cistern C filled with cold water.

"The steam-pipe was adjusted to a small boiler B. When steam was produced, it was admitted into the cylinder, and soon issued through the perforation of the rod, and at the valve of the condenser. When it was judged that the air was expelled, the steam-cock was shut, and the air-pump piston-rod was drawn up, which leaving the small pipes of the condenser in a state of vacuum, the steam entered them and was condensed. The piston of the cylinder immediately rose, and lifted a weight of about eighteen pounds which was hung to the lower end of the piston-rod. The exhaustion-cock was shut, the steam was re-admitted into the cylinder, and the operation was repeated; the quantity of steam consumed, and the weights it could raise were observed; and, excepting the non-application of the steam-case and exter-

nal covering, the invention was complete, in so far as regarded the savings of steam and fuel. A large model, with an outer cylinder and wooden case, was immediately constructed, and the experiments made with it served to verify the expectations I had formed, and to place the advantage of the invention beyond the reach of doubt. It was found convenient afterwards to change the pipe-condenser for an empty vessel, generally of a cylindrical form, into which an injection played, as in fig. 36, and in consequence of there being more water and air to extract, to enlarge the air-pump.

Fig. 36.



"The change was made, because, in order to procure a surface sufficiently extensive to condense the steam of a large engine, the pipe-condenser would require to be very voluminous, and because the bad water with which engines are frequently supplied, would crust over the thin plates, and prevent their conveying the heat sufficiently quick. The cylinders were also placed with their mouths upwards, and furnished with a working-beam, and other apparatus, as was usual in the ancient engines; the inversion of the cylinder or rather of the piston-rod, in the model, being only an expedient to try more easily the new invention, and being subject to many objections in large engines.

"In 1768 I applied for letters patent for my 'Methods of Lessening the consumption of Steam, and consequently of Fuel, in Fire-Engines,' which passed the Seals in Janu-

ary 1769; and my specification was enrolled in Chancery in April following, and was as follows:—

"My method of lessening the consumption of steam, and consequently fuel, in fire-engines, consists of the following principles:—

"First, That vessel in which the powers of steam are to be employed to work the engine, which is called the cylinder in common fire-engines, and which I call the steam-vessel, must, during the whole time the engine is at work, be kept as hot as the steam that enters it; first, by enclosing it in a case of wood, or any other materials that transmit heat slowly; secondly, by surrounding it with steam or other heated bodies; and, thirdly, by suffering neither water or any other substance colder than the steam, to enter or touch it during that time.

"Secondly, In engines that are to be worked wholly or partially by condensation of steam, the steam is to be condensed in vessels distinct from the steam-vessels or cylinders, although occasionally communicating with them; these vessels I call condensers; and, whilst the engines are working, these condensers ought at least to be kept as cold as the air in the neighbourhood of the engines, by application of water, or other cold bodies.

"Thirdly, Whatever air or other elastic vapour is not condensed by the cold of the condenser, and may impede the working of the engine, is to be drawn out of the steam-vessels or condensers by means of pumps, wrought by the engines themselves, or otherwise.

"Fourthly, I intend, in many cases, to employ the expansive force of steam to press on the pistons, or whatever may be used instead of them, in the same manner as the pressure of the atmosphere is now employed in com-

mon fire-engines. In cases where cold water cannot be had in plenty, the engines may be wrought by this force of steam only, by discharging the steam into the open air after it has done its office.

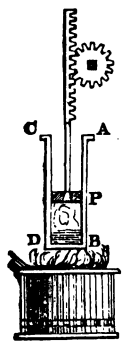
"Lastly, Instead of using water to render the piston or other parts of the engines air and steam tight, I employ oils, wax, resinous bodies, fat of animals, quicksilver, and other metals, in their fluid state.

"And the said James Watt, by a memorandum added to the said specification, declared, that he did not intend that any thing in the fourth article should be understood to extend to any engine where the water to be raised enters the steam-vessel itself, or any vessel having an open communication with it."

Such is Mr Watt's simple account of his beautiful invention—the condenser or refrigerator, which is the characteristic member of the modern steam-engine. The fire-engine of Newcomen possessed only two principal members, to which all the other parts may be considered as mere appendages. The modern steam-engine of Watt consists of three principal members. The two members of Newcomen's engine are the generating apparatus, by which the steam is produced from the water and conveyed to the second member, or the apparatus of application, where the elastic force of the steam is brought in contact with the piston in the cylinder, so as to produce the motion required for the mechanical effect of the machine, and thus directly applied to the work to be done. The third member, added by Watt, is a refrigerator or condensing apparatus, perfectly separate from and independent of the other two, for reconverting the steam, after it has done its duty in filling the cylinder,

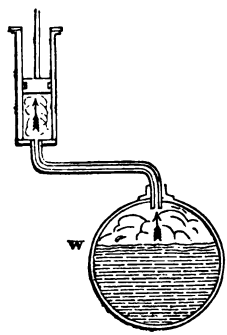
into the liquid from which it had been originally formed. We have, then, the boiler or generator with its appendages, the cylinder or applicator with its appendages, and the refrigerator or condenser with its appendages, —the function to be discharged by the first of these being altogether the reverse of the last; the first producing steam by heat from water, the last producing water from steam by cooling.

Fig. 37. Papin's Apparatus.



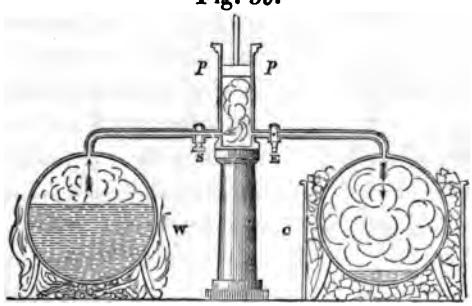
The progress of improvement in the steam-engine may be very well illustrated by comparison with an early project of Dr Papin, who, although he contributed no part towards the production of the modern steam-engine, nevertheless exercised his ingenuity curiously, though fruitlessly, upon the project of deriving mechanical power from the motion of a piston in a cylinder, first of all by gunpowder, and afterwards by steam. In Papin's project, fig. 37, he takes a cylinder, A B C D, containing a piston P, below which he places a fire, so as to generate steam from a little water in the bottom of the cylinder. This steam raises the piston, and it is evident that on the fire being removed, steam will be condensed, and the piston will again be carried to the bottom. Comparing this rude project, in which the steam is alternately produced and recondensed in the

Fig. 38. Newcomen's Apparatus.



cylinder itself, which is alternately warmed and chilled, with the engine of Newcomen, fig. 38, we observe the following important change. The calefaction of the water and generation of steam are carried on in a boiler, W, now removed to a considerable distance from and totally unconnected with the cylinder, except by a pipe of communication opened and shut alternately. Still, however, we have the process of cooling and condensation wholly carried on in the cylinder itself, by means of a jet of cold water playing therein. But let us now make a third step, and we arrive at the model of a machine acting on the principle of Mr Watt's, fig. 39. As we have already, in the machine of Newcomen, a separate heating apparatus, W, conducting the steam in a highly rarefied state to the cylinder, so now let us have a vessel, C, placed on the other side, and let this vessel have first been rendered empty or perfectly vacuous by expelling and pumping out the air; and let us also, for the sake of experiment, put a few lumps of ice and salt in the inside and on the outside of this vessel, surrounding it on every side; and we shall have a refri-

Fig. 39.

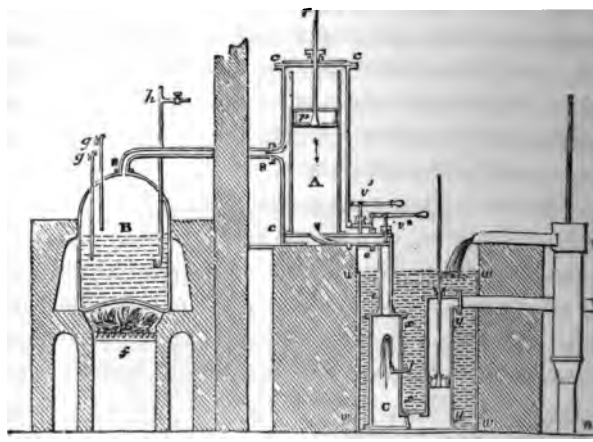


Boiler. Cylinder. Condenser.

gerator as a counterpart to the boiler, and a type of the improvement of Watt.

If we now open the stopcock S, the steam generated in the boiler will rush into the cylinder, pressing the piston upwards; and if the stopcock E be next opened, the stopcock S having been previously shut, the steam in E will instantly escape into the vacuum in the refrigerator, and being condensed into less than a thousandth part of its bulk, will leave the cylinder vacuous. Thus the motion of the piston upwards and downwards is effected by the inventions of Newcomen and Watt, without either applying the fire or the cold directly to the cylinder in which the power is given out. Thus the loss of more than fifty per cent is remedied by the separate condenser of Watt. Papin's scheme was possible but not practicable; Newcomen's was practicable but wasteful. Watt's engine is practical, economical, and complete, both in theory and in practice, as it renders available all the power of heat which the steam contains, with the exception only of the

Fig. 40.



very small part consumed in giving motion to the machine itself.

The foregoing figure (40) approaches very closely to the form of Mr Watt's first engines. Their details are as follows. In the diagram, A represents the cylinder of his earlier engine, B the boiler, and C the condenser, each with its various appendages. The appendages of the boiler B, are of course, *f*, the furnace in which the fuel is burned; *g g*, small pipes for showing the height of the water in the boiler; *h*, a pipe for supplying the boiler with water as its contents pass off in the form of steam; *s s*, a steam-pipe for the purpose of conveying the steam to the top of the cylinder. The appendages of the cylinder are, *p*, the piston, fitting accurately the inside of the cylinder, surrounded with hemp packing, soaked with tallow and oil, so as to be steam-tight; the casing, *c c c c*, which excludes the cold air of the atmosphere from entering into the cylinder to cool it down at the expense of afterwards heating it by the steam; and, instead of allowing it to enter at the top of the cylinder at A, and press down the piston, as in Newcomen's engine, the hot steam is substituted, which, being of an elasticity equal to the atmosphere, presses it, with a force equal to the atmosphere, towards the bottom of the cylinder. After reaching the bottom of the cylinder, the handle of the valve v^1 is raised so as to make an opening for the steam to enter below as well as above the piston; which equilibrium of upward and downward pressure allows the piston once more to rise, in consequence of a counterbalancing weight connected to the top of the piston-rod *r*; and this opening of what is called the steam-valve v^1 continues until the piston once

more reaches the top of the cylinder, when it is closed. The eduction valve v^2, which is at that moment opened, permits the steam to escape suddenly into the condenser, when it becomes water, and leaves the space below the cylinder vacuous, so as to give free space for the piston to be carried down into the cylinder by the pressure of the steam resting always on the top of the piston. These, the casing, piston, piston-rod, steam-valve, eduction-valve, and communicating passages, are appendages of the second great member of the machine, the cylinder, by which the power of the steam is applied to give the required motion to whatever solid machinery may be placed in connexion with the piston-rod. The appendages of the condenser, C, of Mr Watt are as follows. First of all, a large cistern, *w w w w*, of cold water is provided, and furnished continually with fresh supplies of cold water either from a running stream or by means of a pump *m n*, wrought by the engine itself. In this is placed the condensing chamber C *x x*, wholly surrounded by the cold water, but perfectly empty, excepting that a small jet of cold water from the exterior is admitted through a regulated aperture to play in the inside, by which injection it has always been observed that the condensation of the steam is more efficient than when a casing of metal intervenes between the cold water and the steam. The eduction-pipe *e e e*, conducts the steam out of the cylinder by the valve v^2 into the condenser *x x*, where it is reduced back into the water from which it had been originally generated. Now, it must be obvious on a little consideration, that the water which is injected into the condenser must rapidly accumulate there, becoming at the same time warmed by contact with the steam, so as to impede

the process of condensation, and ultimately filling up the interior of the condensing chamber, which should be kept vacuous; and further, that the steam itself, becoming reconverted into water, would in a short period of time accumulate in the condenser and choke it up. Hence a principal and essential appendage of the condenser is a large pump called the condenser-pump, which is essential to its long-continued efficient action, and which withdraws a portion of the accumulated warmed water from the interior of the condenser, and keeps it vacuous; and because there is generally air in combination with the water, and because also air is very apt to insinuate itself by many chinks or crevices into the condenser, this clearing-pump must be capable of pumping out air as well as water. This appendage of the condenser, represented in the preceding figure by *yy*, is generally termed the "air-pump;" a name which imperfectly expresses the functions of the said condenser-pump.

Fire being placed under the boiler, its heat, communicated to the water, rapidly expands that water, and rarefies it into steam, by the addition of six times more than its usual supply of heat. This combination of heat and water, forming the steam, rushes along the steam-pipe into the cylinder casing, and is admitted into the interior of the machine, filling all its chambers and pipes with steam; but that portion of the steam which is in communication with the condenser being instantly chilled by the jet of cold water and the cold sides of the vessels in the cold well, is condensed, and then the valve v^2 being closed so as to admit no more steam into the condenser, and the valve v^1 closed so as to admit no more steam into the lower part of the cylinder below the piston, there remains

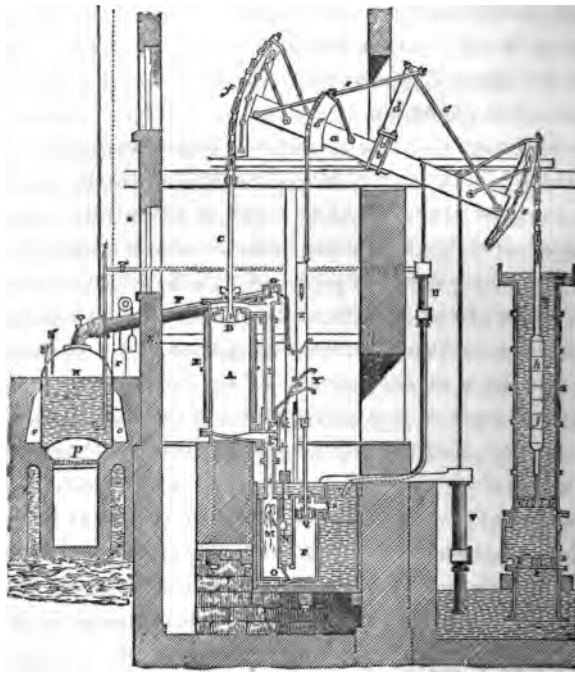
the elastic force of the steam above, pressing it towards the bottom of the cylinder with a force proportioned to the pressure of the steam and the extent of the cylinder. Thus a moving power is generated in the cylinder by the steam, which may be conveyed through the piston-rod *r*, and applied through various mechanism of application to the performance of the required work. The steam which has thus pressed down the piston is now admitted below to neutralize the force of that which remains; and having thus done its duty, is once more annihilated by the opening of the communication into the condenser, into which it rushes, and being almost instantly deprived of the caloric which gave it power and magnitude, there remains nothing except the few spoonfuls of water from which all that volume of steam had arisen, now lying inert at the bottom of the cylinder. This dead water is not yet cold. It is evident that in the primary generation of steam in the boiler, the supply of water must be rapidly diminished by this boiling off, and that this water must somehow be supplied. Now here lies an improvement: this waste, instead of being supplied by cold water, may be better replenished with the water of the condenser, which is highly heated in condensing the steam from the cylinder.

Mr Watt's Engine was first used as a substitute for the engine of Newcomen in pumping up water or draining mines: in 1788 it had attained the form which we have given in the following figure. The engine is represented in fig. 41 as contained within the walls of a building, the anterior portion of which is removed to show the machine. The boiler stands on the left of the figure, on the outside of the building; and on the right of the figure, also on the

outside of the house, are the large pumps, by which the water is raised, and the work of the engine performed. Nearly in the centre of the building stands the cylinder with its appendages, and below these are the cold well and condensing apparatus.

Beginning with the apparatus for generating steam; on the left of the figure, H is the boiler, of what is called the waggon shape, set in a furnace of brick-work immediately over the fire, which rests on the fire-bars at *p*, leaving a very deep ash-pit below; the flame passes away under the concave bottom of the boiler to the further end, and there, instead of proceeding at once up the chimney, returns by *o* on the left side of the boiler, through the brick channel or flue, giving out additional heat to the water, and after passing across the front of the boiler, proceeds along the right-hand flue *o* to the chimney. The draught of the chimney is regulated by means of the damper *r*, which descends into the flue or is raised out of it in any degree by the attendant, and so permits the air to rush with greater or less ease up the chimney. A tube *t*, regulated by a stopcock, comes from a small pump U on the right-hand side of the figure, which raises the warm water discharged by the air-pump, and sends it into the boiler so as to replenish its waste; this pipe and pump being generally named the feed-pipe and tube. The two little tubes proceeding from the water in the boiler, are slender pipes open at both ends, and have external stopcocks, which are always shut except when the attendant wishes to ascertain the height of the water in the boiler, when he opens these gauge-cocks, and, observing whether water or steam issues from them, forms his judgment accordingly. F is the steam-pipe, which

Fig. 41.



carries the steam away from the boiler to be applied to its useful effect in the second great member of the engine.

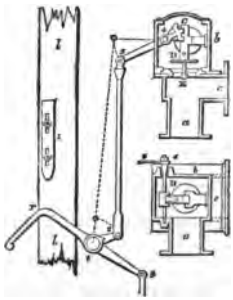
The second great member of the machine is placed in the engine-house. A is the working cylinder, in which is contained the moving piston B, which communicates the force impressed on it by the steam, through the piston-rod *c*, and the chain *f*, to the end of the great lever or working-beam, *f a e*, which is forced up and down around the fixed centre or iron gudgeon *b*, and so raises or depresses the other end of the lever on the right-hand side of the figure, and thus gives the required motion to

h, j, the piston and rods in the barrel of the great pump, in which the work of raising water to a height or from a mine is the useful labour or duty to be performed by the engine. Returning to the cylinder at A, we have now to examine the mechanism by means of which the steam is admitted alternately above and below the piston, through the openings or ports which may be observed on the right-hand side of the cylinder at top and bottom. F is the steam-pipe which brings steam from the boiler to the top of the valve passages, and the pipe I conducts it down to the bottom valves and port at K, and the pipe J forming the eduction-pipe, conducts the steam into the refrigerating apparatus, where it is finally condensed. In commencing to work the machine, the duty of the attendant is to allow the steam to pass freely into all the pipes, passages, and ports, F G I J, &c. filling the cylinder A, the condenser M, and passing out at an aperture O, closed by a valve called the blow-off valve; by means of which operation, the whole of the parts being filled with steam, are rendered vacuous from air, and this preparatory process is called blowing through. At G it is to be observed that there is a steam-nozzle and valve, or regulator, which allows the steam to enter the cylinder at the upper part whenever it is opened, by raising the metallic cover or valve from the opening of the nozzle immediately below, which it exactly fits. At K is a similar nozzle and valve called the equilibrium-valve and nozzle, which admits steam through the pipe I into the bottom part of the cylinder; and the third or exhaustion-valve and nozzle or aperture, allows the final egress of the steam into the condenser. After the engine has been wholly filled with steam, the piston B, being at the top of the cylinder, the injection-cock N is suddenly

opened, and the cold *jet d'eau* playing amongst the steam condenses it instantaneously, forming a vacuum into which the steam from the cylinder instantly rushes, and is in like manner annihilated, leaving the cylinder below the piston equally vacuous; and of course the steam from the boiler, on being admitted by the valve G to the upper side of the piston, instantly presses it down into the vacuum below with a force proportional to the perfection of that vacuum and to the pressure of the steam. Thus the engine makes its first stroke, and raises the water of the great pump on the right of the figure, and the weight of the chain, rod, and bucket, and also a counterpoise *h*, added for the purpose of restoring the beam to its former position, which it does in the following manner. The equilibrium-valve K is opened, and the steam getting admission below the piston, as well as above it, ceases to urge it in either direction, and being thus *in equilibrio*, the piston would remain passively in its place at the bottom of the cylinder; but the action of the counterpoise *h*, and the weight of the water and pump-rods in the large pump on the outside, draw down the outer end of the great lever or working-beam *f a e*, and so raise the interior end *f*, and the piston B to the top of the cylinder. The equilibrium-valve is then closed at K, and the eduction-valve L is opened, so as to allow the steam below the piston to rush down into the condenser and leave a vacuum under the piston, into which it is immediately forced down by the pressure of the steam above A as at first, and raising water at the other end of the beam through a second stroke; and, thus by the continual opening and shutting of the valves by the attendant, the engine performs its work. But we have still to consider the

mechanism by which the valves are shut and opened, and the machine is made to shut and open its own valves

Fig. 42.



For this purpose we have given a separate and enlarged drawing of one of the valves and its working gear:—*l i l* is a part of the air-pump rod, formed of wood, called the plug-frame or plug-tree, on which are two projecting plugs of wood to work the upper and lower valves; one of these plugs is seen at *i*. As the plug-tree moves up and down, the plugs strike the handles or working gear of the valves, and open or shut them at the proper instant. The valves D E are called conical valves, because the small cover D which closes the opening of each nozzle under the valve is slightly tapered downwards so as the more readily to fit its seat, and each is lifted from its seat by a small toothed rack and pinion *c* moved by a spindle from without, communicating by rods with the valve gear at *r*, or at Z and Y in figure 41. When the plug-frame *l i l* descends, the valve *d* is closed by the plug *i*, and the valve K is shut, and the valve L in figure 41 opened by the plug Y.

Returning to figure 41, it will be seen that the condensing apparatus and its appendages are placed almost immediately under the cylinder, and to the right of it. The eduction-pipe J conducts the steam into the condensing chamber M. This chamber is placed in the middle of the cold well, so as to be wholly surrounded by cold water; and through the regulated aperture N a jet of cold water is allowed to play in the inside of it

amongst the steam. P the air-pump is also placed in the cold well surrounded by water; Q the piston or bucket of the air-pump is worked up and down by the piston-rod Q Y Z *g* from the great lever. The valve R closes when the piston descends, and opens on its ascent, allowing water and air to pass into the air-pump, but preventing its return; and the upper valve of the air-pump S allows the escape of water and air outwards, but prevents its return; this valve S leads to the hot well T, from which the feed-pump U draws off a supply of water for the boiler.

"The great advantage of Mr Watt's form is the almost total annihilation of the waste of steam by condensation in the cylinder. The cylinder is always hot, and therefore perfectly dry. This must be evident to any person who understands the subject. By the time that Mr Watt had completed these improvements, his experiments on the production of steam had given him a pretty accurate knowledge of its density: and he found himself authorized to say, that the quantity of steam employed did not much exceed what would fill the cylinder, so that very little was unavoidably wasted. But before he could bring the engine to this degree of perfection, he had many difficulties to overcome. He enclosed the cylinder in another containing steam, and that in a wooden case at a small distance from it, which effectually prevents all condensation in the inner cylinder from external influence; and the condensation by the outer cylinder itself, which was very small, had no other bad consequence than the loss of so much steam as formed the condensed water.

"The greatest difficulty was to make the great piston

tight. The old and effectual method, by water lying on it, was inadmissible. He was therefore obliged to have his cylinders most nicely bored, perfectly cylindrical, and finely polished; and he made numberless trials of different soft substances for packing his piston, which should be tight without enormous friction, and which should long remain so in a situation perfectly dry and very hot.

"After all that Mr Watt has done in this respect, he thinks that the greatest part of the waste of steam which he still perceives in his engines, arises from the unavoidable escape by the sides of the piston during its descent.

"But the fact is, that an engine of this construction, of the same dimensions with a common engine, making the same number of strokes of the same extent, does not consume above one-fourth *or one-third* part of the fuel that is consumed by the best engines of the common form. It is also a very fortunate circumstance, that the performance of the engine is not immediately destroyed, nor indeed sensibly diminished, by a small want of tightness in the piston. In the common engine, if air get in in this way, it immediately puts a stop to the work; but although even a considerable quantity of steam get past the piston during its descent, the rapidity of condensation is such, that hardly any diminution of pressure can be observed.

"When Newcomen's engines are working under loads inferior to their whole power, they are regulated to prevent shocks which would be prejudicial, by lessening the quantity of injection, or by shutting the injection-cock sooner. These new engines may, in some degree, be regulated in the same manner; but it is done more

effectually and economically, first, by limiting the opening of the regulating valve which admits the steam above the piston, and letting it continue so far open during the whole length of the stroke; secondly, by letting it open fully at first, and shutting it completely when the piston has proceeded downwards only part of its stroke; or, lastly, by the use of a throttle-valve, which, acting in the same manner as the floodgate of a mill, admits no more steam than gives the desired power.

"The second of these methods of regulating the power of the engine, forms the basis of what is called the *Expansive Engine*, which renders available the greater part of the power with which the steam would rush into empty space, were the piston acted upon by the whole force of the steam, from the bottom to the top of the stroke, through the whole length of the cylinder—a principle which had first occurred to Mr Watt in 1769, and was adopted in an engine at Soho manufactory, and some others, about 1776, and in 1778 at Shadwell waterworks, and afterwards particularly described in his specification of a patent for several new improvements upon steam-engines, in 1782.

"The construction of this engine is as has been described. The steam-valve is always allowed to open fully; the pins of the plug-frame are regulated so, that that valve shall shut the moment that the piston has descended a certain portion, suppose one-fourth, one-third, or one-half, of the length of the cylinder. So far the cylinder was occupied by steam as elastic as common air. In pressing the piston farther down, it behoved the steam to expand, and its elasticity to diminish. It is plain that this can be done in any degree we please, and

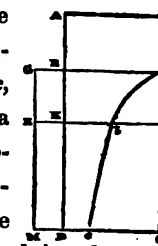
that the adjustment can be varied in a minute, according to the exigency of the case, by moving the plug-pins.

"In the mean time, it must be observed, that the pressure on the piston is continually changing, and consequently the accelerating force. The motion, therefore, will no longer be uniformly accelerated. It will approach much faster to uniformity; nay, it may be retarded, because although the pressure on the piston at the beginning of the stroke may exceed the resistance of the load, yet when the piston is near the bottom, the resistance may exceed the pressure. Whatever may be the law by which the pressure on the piston varies, an ingenious mechanic may contrive the connecting machinery in such a way that the chains or rods at the outer end of the beam shall continually exert the same pressure, or shall vary their pressure according to any law he finds most convenient. It is in this manner that the watchmaker, by the form of the fuzee, produces an equal pressure on the wheel-work by means of a very unequal action of the main-spring. In like manner, by making the outer arch-heads portions of a proper spiral instead of a circle, we can regulate the force of the beam at pleasure.

"Thus we see how much more manageable an engine is in this form than Newcomen's was, and also more easily investigated in respect of its power in its various positions. The knowledge of this last circumstance was of mighty consequence, and without it no notion could be formed of what it could perform, which may be called a discovery of great importance in the theory of the engine. We shall give here Mr. Watt's theory of the expansive engine which we have just described.

"Let ABCD (Fig. 43.) represent a section of the cylinder of a steam-engine, and EF the surface of its piston. Let us suppose that the steam was admitted while EF was in contact with AB, and that as soon as it had pressed it down to the situation EF, the steam-cock is shut. The steam will continue to press it down, and as the steam expands, its pressure diminishes. We may express its pressure (exerted all the while the piston moves from the situation AB to the situation EF) by the line EF. If we suppose the elasticity of the steam proportional to its density, as is nearly the case with air, we may express the pressure on the piston in any other position, such as KL or DC, by K *l* and D *c*, the ordinates of a rectangular hyperbola F *l c*, of which AE AB are the asymptotes, and A the centre. The accumulated pressure during the motion of the piston from EF to DC, will be expressed by the area EF*c*DE, and the pressure during the whole motion by the area ABF*c*DA.

Fig. 43.



"Now it is well known that the area EF*c*DE is equal to ABFE multiplied by the hyperbolic logarithm of $\frac{AD}{AE}$, $= L.\frac{AD}{AE}$, and the whole area ABF*c*DA is $= ABFE \times \left(1 + L.\frac{AD}{AE}\right)$.

"Thus let the diameter of the piston be 24 inches, and the pressure of the atmosphere on a square inch be 14 pounds; the pressure on the piston is 6333 pounds. Let the whole stroke be 6 feet, and let the steam be

stopped when the piston has descended 18 inches, or 1.5 feet. The hyperbolic logarithm of $\frac{6}{1.5}$ is 1.3862943. Therefore the accumulated pressure ABF*c*DA is = 6333 × 2.3862943, = 15112 pounds.

"As few professional engineers are possessed of a table of hyperbolic logarithms, while tables of common logarithms are, or should be, in the hands of every person who is much engaged in mechanical calculations, let the following method be practised. Take the common logarithm of $\frac{AD}{AE}$, and multiply it by 2.3026; the product is the hyperbolic logarithm of $\frac{AD}{AE}$.

"The accumulated pressure while the piston moves from AB to EF is 6333 × 1, or simply 6333 pounds. Therefore the steam while it expands into the whole cylinder adds a pressure of 8781 pounds.

"Suppose that the steam had got free admission during the whole descent of the piston, the accumulated pressure would have been 6333 × 4, or 25332 pounds.

"Here Mr Watt observed a remarkable result. The steam expended in this case would have been four times greater than when it was stopped at one-fourth, and yet the accumulated pressure is not twice as great, being nearly five-thirds. One-fourth of the steam performs nearly three-fifths of the work, and an equal quantity performs more than twice as much work when thus admitted during one-fourth of the motion.

"This is curious and important information, and the advantage of this method of working a steam-engine increases in proportion as the steam is sooner stopped;

but the increase is not great after the steam is rarefied four times. The curve approaches near to the axis, and small additions are made to the area. The expense of such great cylinders is considerable, and may sometimes compensate this advantage.*

"It is very pleasing to observe so many unlooked-for advantages resulting from an improvement made with the sole view of lessening the waste of steam by condensation. While this purpose is gained, we learn how to husband the steam which is not thus wasted. The engine becomes more manageable, and is more easily adapted to every variation in its task, and all its powers are more easily computed.

Let the steam be stopped at	Its performance is mult.
$\frac{1}{2}$	1.7
$\frac{1}{3}$	2.1
$\frac{1}{4}$	2.4
$\frac{1}{5}$	2.6
$\frac{1}{6}$	2.8
$\frac{1}{7}$	3.
$\frac{1}{8}$	3.2
&c.	&c.

"The active mind of its ingenious inventor did not stop here. It had always been matter of regret that one-half of the motion was unaccompanied by any work. It was a very obvious thing to Mr Watt, that as the steam admitted above the piston pressed it down, so steam

* All these calculations, however, proceed upon the supposition that *steam* contracts and expands by variations of *pressure*, in the same ratios that *air* would do.

admitted below the piston would press it up with the same force, provided that a vacuum were made on its upper side. This was easily done, by connecting the lower end of the cylinder with the boiler and the upper end with the condenser."

Hitherto we have considered the condensing steam-engine of Watt in its application to the purpose of working the large pumps used to draw water from mines or to supply reservoirs from a lower level. This, indeed, was the most obvious and immediate application of the steam-engine which was at first introduced as a substitute for the atmospheric pumping engine of Newcomen.

The steam-engine of revolution of Mr Watt was an invention subsequent to the mining steam-engine or "water-commanding machine." Previous to the time of Watt, indeed, there had been a few attempts made to produce a revolving motion by means of steam, such as the case where the engines of Savary and Newcomen drew up water, which, falling upon the buckets of a wheel, produced its revolution. There had also been many attempts to apply the atmospheric pumping engine directly to this purpose—Jonathan Hall, Kean, Fitzgerald, Mr Oxley, John Stewart, and Matthew Wasbrough, had all contrived some means of producing a revolving motion from the reciprocation of the great beam of the pumping-engine; but Watt's engine alone had the power of being rendered an efficient and economical motive power.

We shall take the present opportunity of describing Mr Watt's method of communicating the force of the steam-engine to any machine of the rotatory kind.

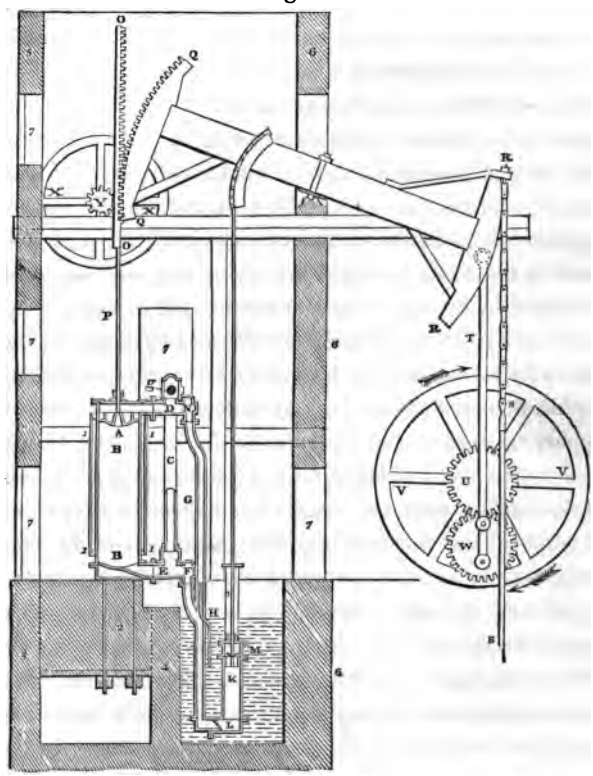
"VV, fig. 44, represents the rim and arms of a very large

and heavy metalline fly. On its axis is the concentric-toothed wheel U. There is attached to the end of the great beam a strong and stiff rod T, to the lower end of which a toothed wheel W is firmly fixed by two bolts, so that it cannot turn round. This wheel is of the same size and in the same vertical plane with the wheel U; and an iron link or strap (which cannot be seen here, because it is on the other side of the two wheels) connects the centres of the two wheels, so that the one cannot quit the other. The engine being in the position represented in the figure, suppose the fly to be turned once round by any external force in the direction of the darts. It is plain, that since the toothed wheels cannot quit each other, being kept together by the link, the inner half (that is, the half next the cylinder) of the wheel U will work on the outer half of the wheel W, so that at the end of the revolution of the fly the wheel W must have got to the top of the wheel U, and the outer end of the beam must be raised to its highest position. The next revolution of the fly will bring the wheel W and the beam connected with it to their first positions; and thus every two revolutions of the fly will make a complete period of the beam's reciprocating movements. Now, instead of supposing the fly to drive the beam, let the beam drive the fly. The motions must be perfectly the same, and the ascent or descent of the piston will produce one revolution of the fly.

"It is proper here to give the history of this invention. I had very early turned my mind to the producing continued motions round an axis, and it will be seen by reference to my first specification in 1769, that I there described a steam-wheel, moved by the force of steam acting in a circular channel against a valve on one side,

and against a column of mercury or some other fluid metal on the other side. This was executed upon a

Fig. 44.



scale of about six feet diameter at Soho, and worked repeatedly, but was given up, as several practical objections were found to operate against it. Similar objections lay against other rotative engines which had been contrived by myself and others, as well as to the engines pro-

ducing rotatory motions by means of ratchet-wheels. Having made my reciprocating engines very regular in their movements, I considered how to produce rotative motions from them in the best manner; and amongst various schemes which were subjected to trial, or which passed through my mind, none appeared so likely to answer the purpose as the application of the crank in the manner of the common turning lathe, (an invention of great merit, of which the humble inventor, and even its era, are unknown.) But, as the rotative motion is produced in that machine by the impulse given to the crank in the descent of the foot only, and behoves to be continued in its ascent by the momentum of the wheel, which acts as a fly, and being unwilling to load my engine with a fly heavy enough to continue the motion during the ascent of the piston, (and even were a counter-weight employed to act during that ascent of a fly heavy enough to equalize the motion,) I proposed to employ two engines acting upon two cranks fixed on the same axis at an angle of one hundred and twenty degrees to one another, and a weight placed upon the circumference of the fly at the same angle to each of the cranks, by which means the motion might be rendered nearly equal, and a very light fly only would be requisite. This had occurred to me very early; but my attention being fully employed in making and erecting engines for raising water, it remained *in petto* until about the year 1778 or 9, when Mr Wasbrough erected one of his ratchet-wheel engines at Birmingham, the frequent breakages and irregularities of which recalled the subject to my mind, and I proceeded to make a model of my method, which answered my expectations; but having neglected to take out a patent, the

invention was communicated by a workman employed to make the model to some of the people about Mr Wasbrough's engine, and a patent was taken out by them for the application of the crank to steam-engines. This fact the said workman confessed, and the engineer who directed the works acknowledged it, but said, nevertheless, the same idea had occurred to him prior to his hearing of mine, and that he had even made a model of it before that time, which might be a fact, as the application of a single crank was sufficiently obvious. In these circumstances I thought it better to endeavour to accomplish the same end by other means, than to enter into litigation, and if successful, by demolishing the patent, to lay the matter open to every body. Accordingly, in 1781, I invented and took out a patent for several methods of producing rotative motions from reciprocating ones, amongst which was the method of the sun and planet wheels described in the text.

"This contrivance was applied to many engines, and possesses the great advantage of giving a double velocity to the fly; but is perhaps more subject to wear, and to be broken under great strains, than the crank, which is now more commonly used, although it requires a fly-wheel of four times the weight, if fixed upon the first axis. My application of the double engine to these rotative machines rendered unnecessary the counter-weight, and produced a more regular motion; *so that, in most of our great manufactories, these engines now supply the place of water, wind, and horse mills; and instead of carrying the work to the power, the prime agent is placed wherever it is most convenient to the manufacturer.*"

"Let us now trace the operation of this machine through

all its steps. Let us suppose that the lower part of the cylinder BB, fig. 44, is exhausted of all elastic fluids; that the upper steam-valve D and the lower eduction valve F are open, and that the lower steam-valve E and upper eduction-valve N are shut. It is evident that the piston must be pressed toward the bottom of the cylinder, and must pull down the end of the working-beam by means of the toothed rack OO and sector QQ, causing the other end of the beam to urge forward the machinery with which it is connected. When the piston arrives at the bottom of the cylinder, the valves D and F are shut by the plug-frame, and E and N are opened. By this last passage the steam gets into the eduction-pipe, where it meets with the injection water, and is rapidly condensed. The steam from the boiler enters at the same time by E, and pressing on the lower side of the piston, forces it upwards, and by means of the toothed rack OO and toothed sector QQ forces up that end of the working beam, and causes the other end to urge forward the machinery with which it is connected; and in this manner the operation of the engine may be continued for ever.

"The injection water is continually running into the eduction-pipe, because condensation is continually going on, and therefore there is a continual atmospheric pressure to produce a jet. The air which is disengaged from the water, or enters by leaks, is evacuated only during the rise of the piston of the air-pump K.

"It is evident that this form of the engine, by maintaining an almost constant and uninterrupted impulsion, is much fitter for driving any machinery of continued motion than any of the former engines, which were inactive during half of their motion. It does not, however, seem

to have this superiority when employed to draw water; but it is also fitted for this task. Let the engine be loaded with twice as much as would be proper for it if a single stroke engine, and let a fly be connected with it. Then it is plain that the power of the engine during the rise of the steam-piston will be accumulated in the fly; and this, in conjunction with the power of the engine during the descent of the steam-piston, will be equal to the whole load of water.

"The engraving here referred to is copied from the drawing of the double engine in the above patent of 1782, and is that of an experimental engine, no others having ever been made exactly similar. I have now added engravings of one of the Albion mill engines, fig. 45, 46, being one of the earliest double engines erected for sale. I do not exactly recollect the date of the invention of the double engine, but a drawing of it is still in my possession, which was produced in the House of Commons when I was soliciting the act of Parliament for the prolongation of my patent in 1774–5. Having encountered much difficulty in teaching others the construction and use of the single engine, and in overcoming prejudices, I proceeded no farther in it at that time, nor until, finding myself beset with a host of plagiaries and pirates in 1782, I thought it proper to insert it, and some other things, in the patent above-mentioned.

"Fig. 45 is a vertical and fig. 46 an horizontal section of one of the Albion Mill Engines.

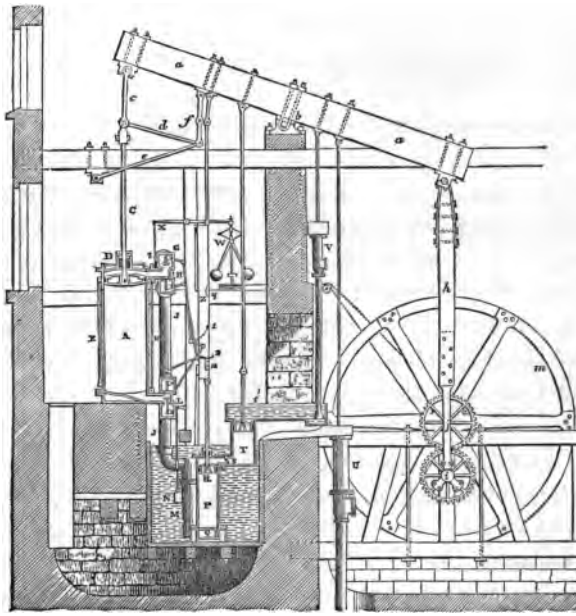
"The steam-pipe F conveys steam from the boiler *n* to the cross-pipe, or upper steam-nozzle G, and by the perpendicular steam-pipe I, to the lower steam-nozzle K. In the nozzle G is a valve, which, when open, admits

steam into the cylinder *above* the piston B, (fig. 45,) through the horizontal square pipe at its top; and in the *lower* steam-nozzle K there is another valve, which, when open, admits steam into the cylinder *below* the piston. In the upper exhaustion-nozzle H is a valve, which, when open, admits steam to pass from the cylinder *above* the piston into the exhaustion-pipe J, which conveys it to the condensing-vessel M, where it meets the jet of the injection from the cock N, and is reduced to water; and, in the *lower* exhaustion-nozzle L, there is also a valve, which, when open, admits steam to pass out of the cylinder *below* the piston, by the eduction-pipe, into the condenser M.

"The piston being at the top of its stroke, the valves G and L are to be opened, and the fly-wheel *m* turned by hand about one-eighth of a revolution, or more, in the direction in which it is intended to move; the steam which is then in the cylinder will pass by L into the condenser, when, meeting the jet of water from the injection-cock, it will be converted into water, and the cylinder thus becoming exhausted, the steam, entering the cylinder by the valve G, will press upon the piston and cause it to descend, while, by its action upon the working-beam through the piston-rod, &c., it pulls down the cylinder-end of the beam, and raises up the outer-end and the connecting rod *h*, which causes the planet-wheel *i* to tend to revolve round the sun-wheel *j*; but the former of these wheels, being fixed upon the connecting-rod so that it cannot turn upon its own axis, and its teeth being engaged in those of the sun-wheel, the latter, and the fly-wheel, upon whose axle or shaft it is fixed, are made to revolve in the desired direction, and give motion to the mill-work.

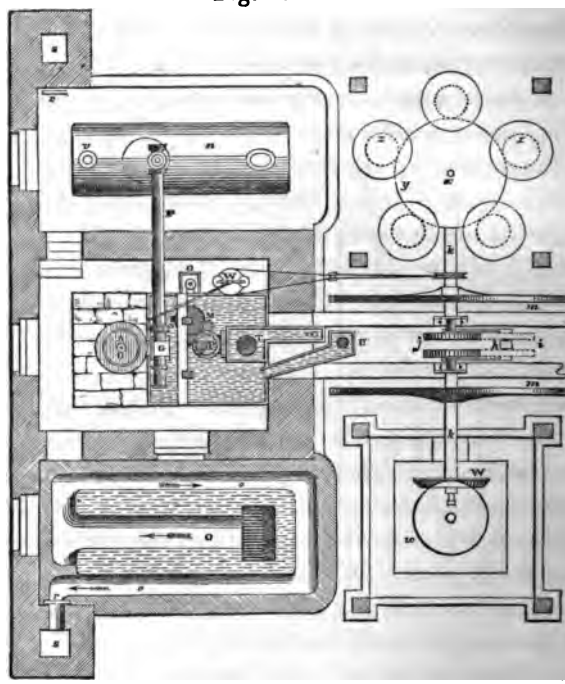
"As the piston descends, the plug-tree Z also descends, and a clamp, or slider *q*, fixed upon the side of the plug-tree, presses upon the handle 1 of the upper Y-shaft, or

Fig. 45.



axis, and thereby shuts the valves G and L; and the same operation, by disengaging a detent, permits a weight suspended to the arm of the lower Y-shaft to turn the shaft upon its axis, and thereby to open the valves K and H. The moment previous to the opening these valves, the piston had reached the lowest part of its stroke, and the cylinder *above* the piston was filled with steam; but as soon as H is opened, that steam rushes, by the eduction-pipe J, into the condenser, and the cylinder *above* the piston becomes exhausted. The steam from the boiler

Fig. 46.



entering by I and K, acts upon the *lower* side of the piston, and forces it to return to the top of the cylinder. When the piston is very near the upper termination of its stroke, another slider *a* raises the handle 2, and in so doing disengages the catch, which permits the upper Y-shaft to revolve upon its own axis and open the valves G and L, and the downward stroke recommences as has been related.

When the piston descends, the buckets R, T of the air-pump P and hot-water pump T also descend. The water which is contained in these pumps passes through

the valves of their buckets, and is drawn up and discharged by them through the lander or trough *t*, by the next descending stroke of the piston. Part of this water is raised up by the pump V, for the supply of the boiler, and the rest runs to waste.

The reader who wishes further details concerning the steam-engine of Mr Watt, will find them in the descriptive portion of this treatise.

The history of the steam-engine ends with the history of Mr Watt's labours. There are, it is true, many parts of the steam-engine that have been altered, simplified, or adapted to peculiar uses and circumstances since his time; but these are matters of minor importance, without which the engine would not have been materially curtailed of its present efficiency. It is a remarkable fact that the steam-engine has scarcely received any very valuable improvement since his time. He, in fact, rendered it a machine nearly perfect. The testimony of Mr Farey upon this subject is explicit, and must be conclusive on the subject with every one who has the means of ascertaining the very high estimation to which the knowledge and practical skill of that excellent writer on the steam-engine most justly entitle him. "It is a circumstance," says Mr Farey, (*Steam-Engine, p.* 473,) "highly creditable to Mr Watt's character, both as an original inventor and as a practical engineer, that his first double-revolving engine, which he made in 1787 at the Albion Mills, performed quite as well as any engine which has since been constructed to employ steam on the same principles. Some important improvements have been made in the construction of modern engines by substituting cast-iron and stone-work in the place of wood, and by putting the

parts together in more substantial modes; but all those essential forms and proportions which affect the performance of the machine, were so ascertained by the first inventor, that no improvement has been since made in them, and every departure from those forms and proportions has impaired the performance in a greater or less degree."

Thus have we taken a rapid survey of the history of the steam-engine. We have omitted the names of many individuals who have distinguished themselves by ingenuity directed to this subject. We have omitted the labours of Gebert, Alberti, Cardan, De Caus, Branca, Morland, Papin, Amonton, Leupold, Meyer, Bosfrand, Gessanne, and a hundred others who have, all in different degrees, expended ingenuity upon the application of steam to the production of mechanical power; and these we have omitted, not because we consider their labours either undeserving of notice or uninteresting to the general reader, but because they have not contributed towards the production of the modern steam-engine, and because an account of their works would rather serve to illustrate the possible varieties of the machine and the fertility of the human mind in mechanical devices, than either to conduct the reader along the stream of historical succession, or render him better acquainted with the nature and mechanical peculiarities of the steam-engine itself.

Part II.—Description of the Modern Steam-Engine.

Of modern steam-engines there are two distinct species—the high-pressure and low-pressure engines. The former is simple, light, and of few parts, generally used for

locomotive engines, steam-carriages, steam-vessels of a light and rapid construction, and such other purposes as require portability or cheapness. The latter is more complex, but more effective; more expensive in original construction, but more durable and more economical in consumption of fuel. The first is more commonly in use in America, the latter in this country. The high-pressure engine is sometimes also called the non-condensing steam-engine, to distinguish it from the low-pressure engine, which is also called the condensing steam-engine; but there is sometimes a combination effected of some of the parts and principles of both these species, in what is called a high-pressure condensing engine, by which, for certain purposes, the peculiar merits of both species are combined in the same machine.

Of these two sorts of steam-engine, it is remarkable that the more elementary and simple—that which is the more easily conceived and understood—was not invented and brought into practical use until long after the other kind had been very extensively used and made known by its inventor, James Watt. It appears to us, that we are to consider Oliver Evans of Philadelphia as the inventor of the modern high-pressure engine. Before 1786 he had contrived and made experiments upon a high-pressure engine, which seems to have been in all essential respects similar to our own. Indeed, it appears that the Americans have taken the form and arrangements of their engines from Evans, as implicitly as in this country we have adopted those of Watt. The history of Evans consists almost entirely of the romance of real life. Sanguine and energetic, he continually encountered difficulties only to overcome them, and to encounter re-

newed disaster and disappointment, till he at length died of a broken heart. To him we attribute the rapid advancement of America, at the commencement of the present century, in all that relates to the introduction of the steam-engine in its multifarious applications, and especially in steam navigation. He had awakened in that nation a lively sense of the advantages which they were likely to derive from the introduction of the power of steam, and placed in their hands an instrument well fitted for their use, and which they were not slow to adopt and apply.

The high-pressure or non-condensing engine consists of *two* principal members, *generator* or *boiler* and working *cylinder*, each with sundry appendages. The low-pressure or condensing steam-engine consists of *three* principal members, *generator*, *cylinder*, and *refrigerator* or *condenser*, each with sundry appendages.

The generator and working cylinder, with their appendages, are nearly the same in both kinds of steam-engine, the presence of a condenser or refrigerator forming the principal and almost only distinction of the second species. By this second species the steam is returned into its first state of water, thereby effecting a saving of heat and of mechanical power; whereas, in the first form of engine, the steam, after performing a certain portion of its labour, is discharged into the open air as useless; a process which can only be advisable in circumstances where the labour and apparatus for condensing would cost more money, and cause more inconvenience than would countervail the loss of fuel and heat and power.

As, therefore, the high-pressure non-condensing steam-engine is simpler in its action and construction than the

low-pressure condensing engine, it is convenient to consider, in the first instance, its mechanism and management, and afterwards, how far it may require to be modified in order to acquire the advantage of condensation.

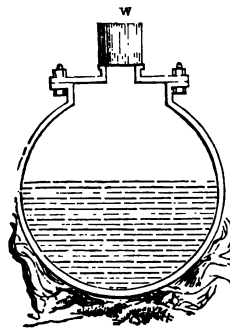
The High-Pressure Non-Condensing Steam-Engine.

The elastic force of steam is a phenomenon with which we become acquainted very early in life. We see that when water boils furiously in a kettle or caldron which is closely fitted by a lid or cover, it has a tendency to raise it up or drive it off with considerable force; and that the steam, collecting in the upper part of the vessel, rushes with considerable velocity out of any crevice or pipe which communicates with the open air.

The force of the steam which is thus issuing from the spout of a kettle or crevice in the cover of a caldron is comparatively slight; and the steam which thus rises from boiling water is called low-pressure steam. But if we stop up the spout and close the cover with accuracy, so as to confine the steam within the kettle or boiler, the water will become hotter and hotter, and the steam stronger and stronger, until it will either force up the cover with violence, or altogether burst asunder the sides of the boiler. In this confined and heated state the steam acquires, from its properties, the descriptive appellation of high-pressure steam.

Engineers are in the habit of reckoning the force of high-pressure steam by a very simple expedient. They place a weight such as W (Fig. 47,) upon a hole on the top of the boiler. This hole being square, and an inch in length and breadth, and the weight being equal to one pound when the steam is strong enough just to blow the

Fig. 47.



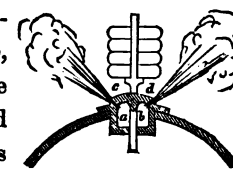
weight off the hole, they call that *steam of an elastic force equal to one pound on the square inch.* They then place a weight of two pounds upon this hole of a square inch, and continue the heat until the steam just blows it off, and that is called *steam of the pressure of two pounds on the square inch.* And, in like manner, when steam is confined and heated until it acquire force enough to blow weights of three, four, five, fifteen, or fifty pounds off an aperture of not more than a square inch in extent, that is technically called *steam of the elastic pressure of three, four, five, fifteen, and fifty pounds on the square inch.* It is difficult to say whether there be any limit to the elastic force which steam may acquire from continued heat and confinement: it is known to be even as powerfully elastic as gunpowder, and pressures of one thousand pounds an inch have been produced.

The pressures generally adopted for high-pressure engines are from fifteen to one hundred and twenty pounds on the inch. Of course, when there is a given pressure on any one inch of the surface of a boiler, there will be the same on every other inch of surface; and if the aperture under the weight be any number of times greater than one inch, it will just require so much the more weight to keep it closed. The standard by which the pressure is reckoned and calculated is, however, always the square whose side is one inch.

Safety-valve.—By placing a movable weight on an aperture of given size in this manner, the engineer not only ascertains the amount of the elastic force of the steam tending to burst the boiler, but also constructs a valve by which to avert the danger of an explosion of the boiler, Dr Desaguliers relates a circumstance which happened very early in the history of the steam-engine, when, for want of proper precautions of this nature, "the steam burst the boiler with a great explosion, and killed the poor man who stood near, with the pieces that flew asunder, there being otherwise no danger, by reason of the safety-valve being made to lift up and open upon occasion." Now, a given weight of lead or iron laid on a hole in the top of a boiler so as to close it, is a sufficient and common form of safety-valve; for whenever the pressure of the steam becomes sufficient to raise the weight, it escapes through the opening into the air without doing any mischief. A large weight of lead, simply placed on the opening, is a very common and simple mode of providing for the safety of the apparatus.

But this plan becomes inconvenient when the pressure is high and the weight great, because it then becomes so high as to be unsteady; and, in order to remedy the inconvenience, what is called a *valve* is used, separate from, and in addition to, the weight, as shown in the accompanying diagram, fig. 48. A valve-seat *a b*, formed of cast brass, is fixed in the aperture, and is accurately fitted by the valve itself *c d*, the edges of which, at *c* and *d*, are carefully turned and tapered, so as to fit the neck of *a b*, and ground in its place

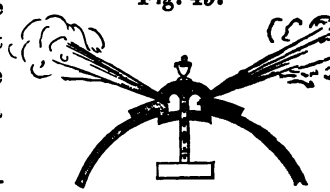
Fig. 48.



with emery powder, which makes it perfectly steam-tight. A spindle protrudes downwards from the valve through a guide which keeps it in a straight line, and prevents it from falling on one side of the valve after having been raised. This same spindle, rising upwards, carries upon a cross-bar a series of large cylindrical weights which may be increased or diminished in number as the case may require.

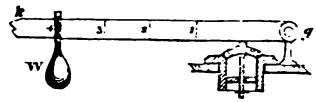
It is a practical fault of this valve that the tall erect spindle may easily become bent or injured by accident, and also that the weight upon it may too easily be handled, so as wantonly to be increased; hence, a safety valve, with an internal weight, has been contrived in the following shape. A conical valve is placed in its seat in every respect as formerly, only the spindle does not rise up but hangs down among the steam, terminating in a chain and weight.

Fig. 49.



In all of these modifications the weight on the safety-valve becomes large and cumbrous when the pressure is high; and a contrivance was devised very early in the history of steam to obviate the inconvenience of this plan, under the name of the lever safety-valve. Instead of placing a great series of weights on the valve itself, a single weight is hung on the end of the longer arm of a lever so as to produce an effect proportional to its distance, and this lever being graduated, shows the amount of the effect which is thus produced. In the figure, the valve, valve-rod, and spindle are all arranged as formerly: but a lever, *g k*, rests

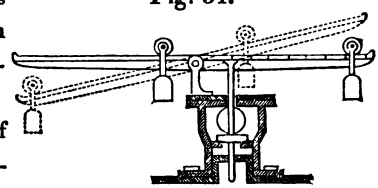
Fig. 50.



on the top of a small hemispherical button on the valve; and the one end *g* being a fulcrum, the weight W is suspended by a ring from any point of the lever. When, at the point 4, as in the figure, its effect on the valve is four times as great as if directly upon it. The effect of the lever's own weight will, in this case, be also equivalent to a certain number of pounds on the valve, which, being properly estimated, the lever safety-valve may be used to indicate with accuracy the pressure of the steam.

Another form of valve has been proposed, as indicating still more correctly the point at which the pressure of the steam is equal to the pressure on the valve. It is a cylinder or flat valve, acted on by a lever and weight; and there are weights on opposite sides of the lever, which has also equal arms. These weights rest on light rollers so as to run down from their places and release the steam entirely, whenever its pressure reaches the prescribed limit. This is the valve of the French Academy and Franklin Institute.

Fig. 51.



Another form of valve, also cylindrical, was used by Mr Southern for his delicate experiments on high-pressure steam. The cylinder of the valve-seat used in the former figures is prolonged upwards, so as to form a vertical cylinder or tube, in which a plug of metal is exactly fitted. This plug is ground with great care, so as to move freely but steam-tight in the cylinder; and a rod from the cylinder passes

up through a hole in the top, and is kept down by a lever and weight. A hole in the cylinder allows the steam to escape whenever the pressure on the valve upwards exceeds the pressure of the lever and weights in the opposite direction. The indications of this instrument are found to be very precise.

Fig. 52.

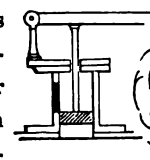


Fig. 53.

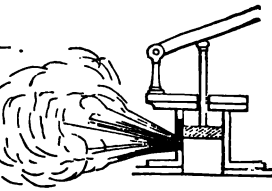
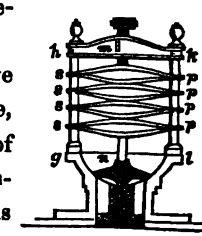
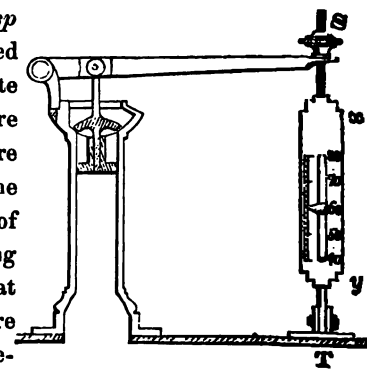


Fig. 54.



Another species of safety-valve has of late years come into use, called the spring-valve. It is of two kinds, with a lever and without it. The form without the lever is represented in the first of these diagrams, fig. 54. A series of bent springs, *sp sp sp sp*, &c., are placed alternately in opposite directions, in the square frame *g h k l*, and are forced down upon the valve at *n* by means of a cross-bar *k h* acting at *m*—a small screw at *m* adjusting the pressure by compressing or releasing the spring.

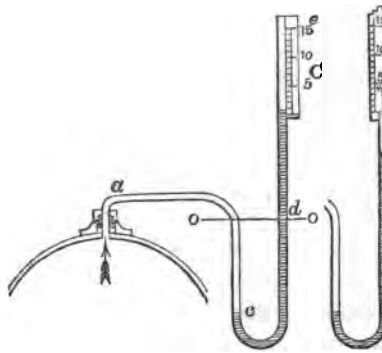
Fig. 55.



The other form of spring safety-valve interposes a

lever between the safety-valve and the spring. S T, fig. 55, is what is commonly called a Salter's spring balance, the box $x\,y$ containing a spiral spring, which is compressed in the box when the end S is drawn away from, or raised above the point S. The finger-screw S adjusts the degree of tension on the end of the lever. The two last species of safety-valve are used in locomotive steam-engines.

Fig. 56. Fig. 57.



A totally different method of indicating the pressure of steam in a boiler, is by means of what is called a *mercurial gauge*, communicating with the boiler. Mercury is poured into a bent tube, one end of which springs from the boiler, and the other end is exposed to the air, so that the steam by its pressure raises the mercury in the straight limb of the tube to a height above the level proportioned to that pressure. In the figure, *a c d e* is the bent tube, communicating with the boiler at *a*, and open at the end *e*, the steam presses on the end *c* of the mercury, and raises the other extremity of the fluid to the height C. From calculating the weight of mercury, it is reckoned that, for every pound of pres-

sure of the steam in the boiler, there is an inch of mercury raised in the tube; so that, if the space *d* C be nine inches, a pressure of nine lbs. on the square inch in the boiler is indicated. Sometimes also a small float of iron is placed on the mercury, which, carrying a slender rod with an index, points the elevation of the mercury on a scale above the gauge. It is evident that this instrument also acts as a safety-valve, inasmuch as the steam, when too strong, must force the mercury entirely over the top of the tube, and make its escape. A double pipe, on a larger scale, with water in it instead of mercury, would answer the same purpose equally well; only the water would rise one foot and an inch for every pound of pressure of steam in the leg of the double tube, and twice that quantity if the tube were single; which would give a scale of $16\frac{1}{2}$ feet in a double tube, or 33 feet in a single tube, as the column of water raised above the level by a pressure of 15 lbs. on the square inch.

It is convenient to reckon the pressure of steam in larger numbers than pounds, and the quantity that has been fixed is a weight of 15 lbs., or a stone weight, per square inch; and to this weight the name of an atmosphere of pressure has been given, simply because the common atmosphere of air presses on all bodies with a weight of 15 lbs. on the square inch. Thus steam having a pressure of 15 lbs. on the square inch, is called high-pressure steam of the elastic force or strength of one atmosphere. High-pressure steam having a pressure of 30 lbs., is said to have an elastic force of two atmospheres, 45 lbs. of three atmospheres, &c. Sometimes, however, a nomenclature rather different is adopted, and the common steam of boiling water, which exerts no further

pressure than merely to balance the atmosphere, is called steam of one atmosphere; and in this case the elastic steam which has been called one atmosphere would be considered as two atmospheres. This nomenclature will be rendered evident by the consideration of the following table :—

High-Pressure Steam of

0 lbs. on the square inch is called	0 atmos.	or 1 atmos.
15	1	2
30	2	3
45	3	4
60	4	5
75	5	6
90	6	7
105	7	8
&c.	&c.	&c.

Owing to this degree of ambiguity in these technical measures of pressure, it is always necessary to observe, and to specify, whether the pressure spoken of is pressure total or excess above the atmosphere of air. If, for example, four atmospheres be specified, it must be considered whether four atmospheres above the pressure of the atmosphere be meant, as in the first column of the table, or four atmospheres including the atmospheric air pressure, in which case the number in the second column is meant; for, in the former case, high-pressure steam of 60 lbs. on the square inch is meant, and in the latter high-pressure steam of only 45 lbs. above the atmosphere.

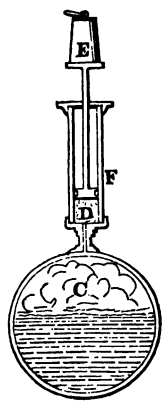
Such are some of the various methods by which the elastic force of high-pressure steam in a boiler may be estimated and shown. We have next to consider the

manner in which that force may be applied to the useful purpose of forming a high-pressure steam-engine.

We have already seen how the force of steam, confined in a close boiler and heated until it acquires great elastic force or high pressure, acts upon every point of the surface in which it is enclosed, tending to press it asunder; and how, by sufficiently confining and heating it, weights of five, fifteen, or fifty pounds, resting on only a single square inch of surface, may be supported and upraised. To apply this force to the raising of great weights, is the object of the high-pressure steam-engine; and it has been calculated that 6 lbs. of coal, applied in heating 6 gallons of water into steam, has sufficient force to perform the most arduous labour of a man, for a whole day.

One of the simplest and earliest applications of the force of high-pressure steam to raising weights, is given by Jacob Leupold, in his *Theatrum Machinarum Hydraulicarum*, Leipzig, 1725. This we have copied from his work in the accompanying figures. We have already seen that the boiler C, fig. 58, being placed on a fire, the elastic force of the steam will raise a weight resting on an aperture. Now, if we conduct the steam in a pipe into any other vessel, such as the cylindrical tube F, in which there is a piston or movable plug D, on the top of which rests the weight E, by a metallic rod E D, connected with the piston, and passing freely through a hole in the top of the cylinder, it is manifest that when the steam becomes strong enough to overcome the pressure of the weight,

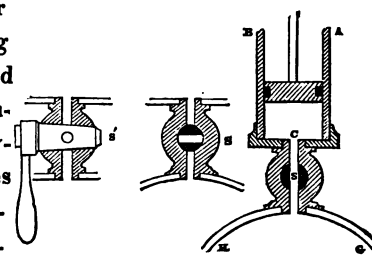
Fig. 58.



it will raise up the piston to any required height. If the weight be 15 lbs., and the size of the surface of the piston one square inch, and if the pressure of the steam be equal to any thing more than one atmosphere of elastic force, it will overcome the weight and raise it. If the surface of the piston were double the size, or two square inches in extent, then each inch would be acted on by a force of 15 lbs., and the same elastic force acting on two inches would raise double the weight, or 30 lbs., and so on for any number of square inches; so that, if the piston were a circle of four inches in diameter, which would have a surface of about 12 square inches, on each and all of which a pressure of 15 lbs. was sustained, there might be a total weight of 12 times 15 lbs., or 180 lbs., sustained and raised to the top of the cylinder. The boiler being removed from the fire and allowed to cool down again, the piston might again descend, and this operation be repeated as often as necessary.

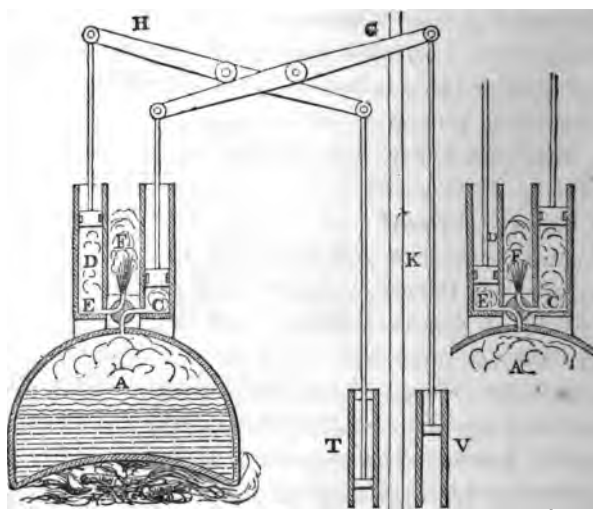
But a more convenient form of the apparatus is that which Leupold gives in the next figure,—in which it is unnecessary to remove the fire. The boiler G H, fig. 59, having a constant fire placed under it, the communication with the cylinder A B C takes place through a passage capable of regulation by a stopcock S, which is shown at S′ as shut by turning the handle. This stopcock is similar to that commonly used for regulating the flow of liquors in vessels

Fig. 59.



of any kind ; a small conical plug S′ stops up the passage entirely, but being perforated in one direction, allows the communication to take place whenever that perforation is turned round into such a position as to form a continuation of the channel. By this means it is provided that this stopcock shall remain in the position, S′ being closed, until the steam has collected in the boiler a sufficient elastic force, after which it is allowed to pass up into the cylinder, by turning the stopcock into the position S when the steam entering the cylinder pushes up the piston and the piston-rod by which the great weight E is raised as before. The piston will then be allowed to descend to the bottom, by allowing the cylinder gradually to cool, when the weight may again be raised as at first ; and so on for any number of operations.

Fig. 60. Fig. 61.

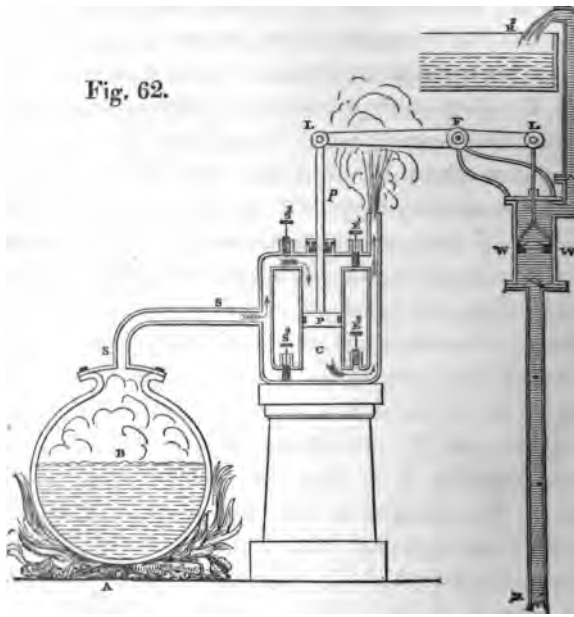


But the most perfect of Leupold's machines is that represented in the figures, 60, 61. It is a true water-pumping high-pressure steam-engine; a machine which might be efficiently used without any alteration at the present day, only the modern machines are calculated to do the work with a smaller expenditure of fuel. Two pumps for raising water are directly worked by steam, by connecting the handles of the pumps with the pistons of two high-pressure cylinders, in such a manner, that when the pistons are raised by the steam the water is forced up in the pump-pipe. T and V are the barrels of two pumps placed in a reservoir, from which water is raised through the joint-pipe K; G and H are the handles or levers by which the pumps are worked. The pistons of the steam-cylinders C and D are attached to the ends of the levers. In figure 60, at A C the steam is shown in the act of entering into the cylinder C, and pushing up the end of the lever G, so as to force the water; and in figure 61 the steam is shown entering into the cylinder D, to work it. This change is effected by turning round the disc A F into the position R S, which reverses the passages, as will appear on examination. It is to be noticed, that while the steam is entering the cylinder C through A C, the steam from the cylinder D is escaping through E F into the open air; and that in the second sketch of the valves, the steam is passing into the cylinder D through A E, and passing out of the cylinder C through C F. The action of this *four-way stopcock* is very simple and beautiful, and deserves to be carefully studied. By continually turning it round in one direction, communications are simultaneously effected between the boiler and each of the cylinders alternately,

and between each cylinder and the open air. We shall afterwards revert to this mechanism.

The modern steam-engine of high pressure is in many respects analogous to the machine of Leupold. It will be readily understood by the study of the few following illustrations. The engine is called double-acting, because

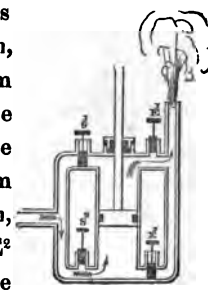
Fig. 62.



the steam not only enters the cylinder below the piston to raise it, but also above the piston forcibly to depress it. The boiler B is placed on the left of the figure; the pump, for raising water from the reservoir R to the reservoir R^2, is on the right of the figure; and the cylinder is placed in the middle. From the boiler a *steam-pipe* S S S^1 S^2 proceeds to the upper and lower parts of the

cylinder C; and from the right-hand side of the cylinder two short *eduction-pipes* E^1 and E^2 carry off the steam into the open air, after it has performed its duty. The piston P is accurately fitted into the cylinder, so as to be air and steam tight, and the piston-rod *p* is made to carry with it the end of the lever L F L, and work the pump W W. Perhaps the only difficulty that is felt in understanding the mechanism of the double-acting steam-engine, lies in the construction and operation of the valves. S^1 S^2 E^1 E^2 are four plugs, each capable of exactly filling up the passage in which it is placed, like S^2 E^1, or of being withdrawn from it, like S^1 E^2. Therefore it is evident that in figure 62, the steam has free access through the upper port S^1, into the cylinder above the piston, so as to press it down. In fig. 63, the case is shown reversed: the valve S^1 is shut down, allowing steam to enter only by S^2, the lower valve, so as to enter at the bottom of the cylinder and force the piston up. The arrangement of the eduction-valves E^1 and E^2 is also to be observed. In fig. 62, where S^1 is open and S^2 is shut, E^2 is also open, and E^1 is shut; so that, while steam enters freely by S^1 on the upper side of the piston, pressing it down, there is a free passage for escape of steam from the under side of the piston, by the bottom passage, through E^2 to the open air; and when the whole is reversed, as in fig. 63, the steam-valve S^2 at the bottom being opened for ingress of steam below the piston, E^1 gives free egress to what was formerly admitted above,

Fig. 63.



so that it may now pass along the passage E^1 into the open air. Thus, then, by opening and shutting alternately each of the two pairs of valves, first the under steam-valve and upper eduction-valve, and then the upper steam-valve and under eduction-valve, so as first to allow steam to enter above and escape below, and then to get in below and out above, the one pair being always shut when the others are open, the whole effect is accomplished.

It is an object of great importance to the precision of a machine's operation, that it should be automatic; that is to say, that it should not require for its successful action the continual attention and unvarying assistance of an attendant. In the machine which we have just described, the valves are opened and shut by the attendant. With the following simple mechanism the valves are opened and shut by the machine itself:—

Fig. 64.

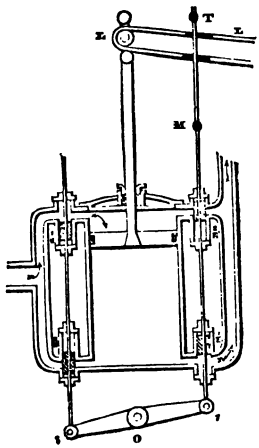
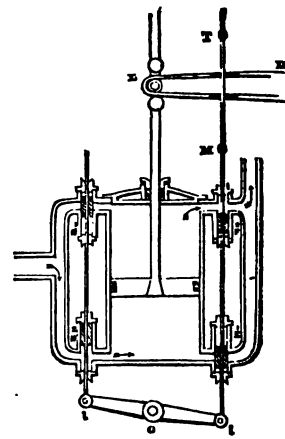


Fig. 65.



The two valves S^1 and S^2 are connected together by a

straight rod, and the two eduction-valves E^1 E^2 by another straight rod; these valve-rods are made to rest on opposite ends of a lever *l l*, which turns on a centre O. By this simple arrangement it is brought about that the pair of valves S^1 S^2 being depressed, as in fig. 64, the other pair E^1 E^2 are raised; but when, as in fig. 65, S^1 S^2 are raised, E^1 and E^2 are depressed, while at the intermediate position both are situated similarly to each other. In the next place it is to be noticed, that the rod E^1 E^2 is prolonged to T upwards, and that it carries two projections fixed to it at M and T. These projections are struck by the lever L L as it rises and falls. When, in fig. 64, the lever is making its downward stroke, it comes on the plug M; and pushes it down, first into the middle position, and then into the position of fig. 65. The steam then entering below, raises up the piston to the top of the cylinder, and with it raises also the lever, which striking on the upper plug T, carries it upwards, raising the eduction-valves E^1 E^2, and allowing the opposite valves S^1S^2 to descend into the position of fig. 64, as at first. This operation being repeated, so that at the end of each upward and downward stroke, the descent and ascent of the piston and lever prepare the valves for producing the inverse effect, and giving the next succeeding stroke, the machine becomes independent and automatic. It is rather curious that these simple valves, now described, are the latest improvements that have been introduced in the steam-engine.

Considerable ingenuity has been expended on the valves and passages of the steam-engine, for the purpose of forming all these communications by means of a couple of passages, instead of four. The following diagrams

are designed to explain the manner in which this has been effected, by means of a four-way cock, similar to that introduced by Leupold into his high-pressure engine. For this purpose the steam-pipe S, the eduction-pipe E, and the pipes of the upper and lower ends of the cylinder, communicating with it above A and below B the piston, are all brought to the circumference of a single circle, so as to form a St George's cross, as in fig 66. A metallic circular disc O P O B, with two curved channels communicating at successive quadrants of a circle, as shown in fig. 67, is inserted in this circle, so as to fit it exactly, and to be moved round by a protruding handle H. In fig. 68, this valve is represented *in situ*, a communication being formed from S to A, and the other from B to E; and, in fig. 69, the handle being pushed

Fig. 66.

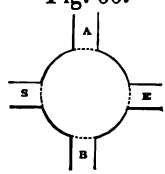


Fig 67.

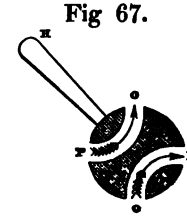


Fig. 68.

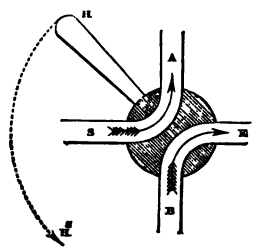
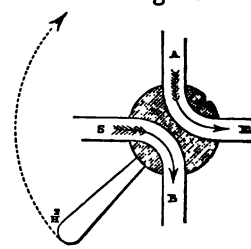


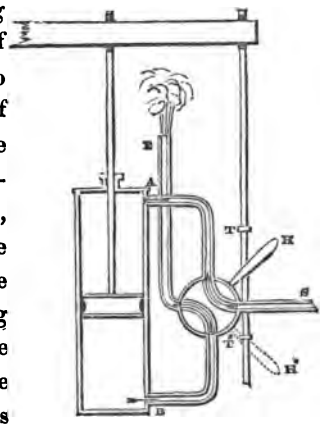
Fig. 69.



down, a communication is made betwixt S and B, and between A and E. The means of effecting this commu-

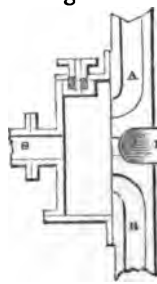
nication is given in fig. 70. A vertical rod T T^2 being suspended from the end of the great lever, with two plugs T T^2, by means of which the handle H of the valve is raised, in that position the steam enters at S, and passes up through the superior passage into the top of the cylinder, forcing the piston down, while the steam already below the piston finds free egress along the inferior passage B, through the valve, and escapes by the eduction-pipe E into the open air. Just before the piston gets to the bottom of its stroke, the plug T strikes the handle H into the position H^2. The steam before let in above the piston suddenly escapes by the port A, through the valve, into the eduction-pipe E, while by the same motion a connexion has been effected between S and B, so that the steam now enters below the piston, again to raise it up until the plug T^2 strikes the handle H^2 upwards once more into the position H, as at first, when the piston once more descends; and this process is repeated to the end.

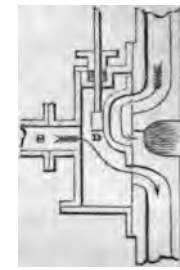
Fig. 70.



We shall next describe a kind of valve which is more commonly in use than either of the former, and by which the changes in the direction of the steam are still more simply effected. In this case all the four passages are united in a square box called a valve-box, or valve-chest, as in fig. 71; S E A B being the steam, eduction,

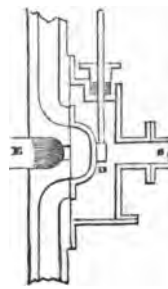
Fig. 71. Fig. 72. Fig. 73.

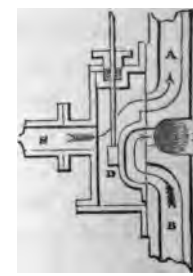




upper, and lower passages. Into this box is introduced a small valve or cover D, fig. 72, which is of such a size as at one time to leave open only one of the three openings on the right; so that, by covering two of the openings, A

Fig. 74. Fig. 75.





and E, as in fig. 73, the steam from S can only find its way through B into the lower part of the engine, while the steam already in the upper part of the cylinder can find its way, below the valve D, into the eduction-pipe E, so as to escape into the air. The valve is next shown in fig. 74 in its middle position, where all the three passages are closed, preparatory to reversing the direction of the steam, as in the third position when it slides from the upper port A, as is shown in fig. 75, so as to allow

the steam to enter above the piston and press it down, while the steam formerly below the piston escapes into the air through the passage B, under the valve D, by the eduction-pipe E. This valve, named from its figure the D-valve, is also worked by the machine itself, either by some of its moving parts striking plugs on a rod which is fixed to the valve, or by some of the other apparatus which will afterwards be described.

Another form of valve is that called the long slide or long D-valve, the invention of Mr Murdoch, which gives the advantage of shutting off the steam, close to its ingress into the cylinder; and so saving what in the common short D-slide is lost in the passages from A and B to the ends of the cylinder. It is formed thus. The valve-chest extends along the side of the cylinder. It is shown in fig. 76, without the valve. In figure 77 the long D-slide valve is shown separately. It is a pipe extending along the whole length of the cylinder. Towards the ends, this pipe is almost semicircular, its flat side, which forms the diameter of the circle, being a narrow flat plate capable of covering the opening or port of the cylinder.

Fig. 76.

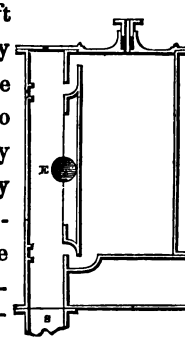


Fig. 77.

This pipe is left open, and perfectly clear from the one end to the other, so that the steam may traverse it freely lengthwise. The semicircular ends are polished, and rendered truly cylindri-

cal, that the packing in the valve-chest may embrace them perfectly. The steam-pipe is represented as entering the valve-chest from below at S, and the eduction-pipe in the middle as at E. In this valve-chest are placed packing-boxes, as they are called, immediately opposite to the ports of the cylinder. They contain a quantity of soft elastic hemp, soaked in oleaginous matter, the object of which is to press against the outside of the slide-valve when in its place, and make steam-tight partitions in the valve-chest between the middle and ends of the valve, so that no communication of steam can take place between the middle and the two ends.

Fig. 78.

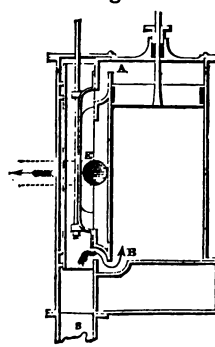
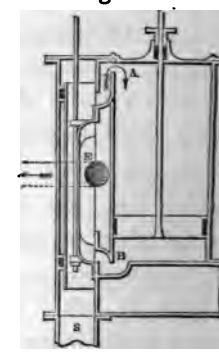


Fig 79.

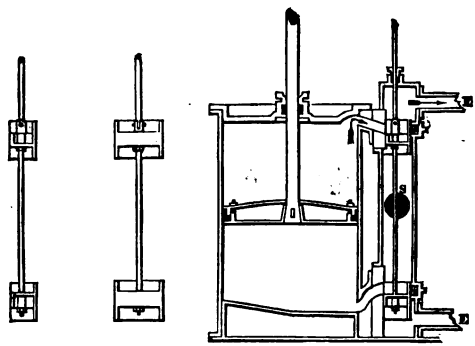


In the figures 78 and 79, the valve is shown *in situ*. In figure 79, the steam from S rises up along the centre of the slide, and enters the upper port A, while the steam in the under part of the cylinder has free egress through B to the eduction-pipe E. In figure 78, the steam has free access to the lower port B, while the steam already above the piston has free egress through the upper port A to the eduction-pipe E. In

this species of slide, there is scarcely any loss of steam in the passages, as it is cut off close to the cylinder.

Instead of the long D-slide, which is very heavy on a large scale, two short slides, similar to its two ends, and connected together by bars, have been used in the following form. Fig. 80 is a section of the slide, fig. 81, a

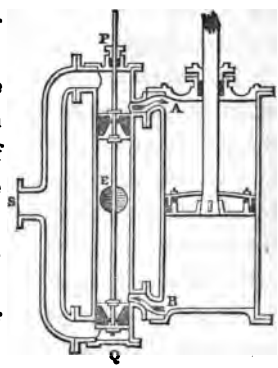
Fig. 80. Fig. 81. Fig. 82.



face view; and fig. 82, a section of the cylinder with the valves in their place.

In this case, however, there are two eduction-pipes E E instead of one, as formerly, and the steam-pipe enters between the valves.

Fig 83.

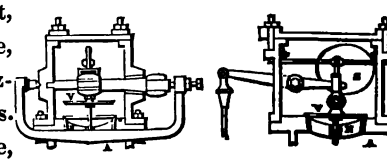


A cylindrical slide-valve of the following form is in use in a considerable number of engines, and works well in those cases which we have had an opportunity of examining. The valve-chest is an upright cylindrical pipe P Q, the inside of which is bored truly cylindrical,

and is exactly fitted by two metallic cylindrical plugs, which are ground so smooth in their places as to be steam-tight. It will be apparent from the figure that these two plugs being raised and depressed by the valve-rod which connects them, will effect the same purpose as the former valve.

The conical valve is a species of valve introduced by Mr Watt, and improved by his assistant Mr Murdoch, from whom the steam-engine of Watt has received many valuable appendages, and much of its practical perfection. It has been applied in two forms. Mr Watt's own form, the earlier one, is given in the following figures. For a single engine four valves are required. One of them is represented separately in figures 84, 85, which are vertical sections through the valve, at right angles to each other. The valve is shown open in fig. 84, and shut in 85. S is the entrance of the steam, A the port, V the conical valve, and N the seat or nozzle which it covers. On a cursory glance, it is evident that when the conical cover V of the aperture N is up, as in the first diagram, the steam has free entrance; and when it is closed, the steam will merely press the valve down into its seat, without obtaining an escape from the nozzle. The manner in which this is effected for all the passages, is shown in the following perspective diagram, fig. 86. *a d d* is the steam-pipe from the boiler; *g g* the eduction-pipe; *b* the upper steam-valve; *e* the lower steam-

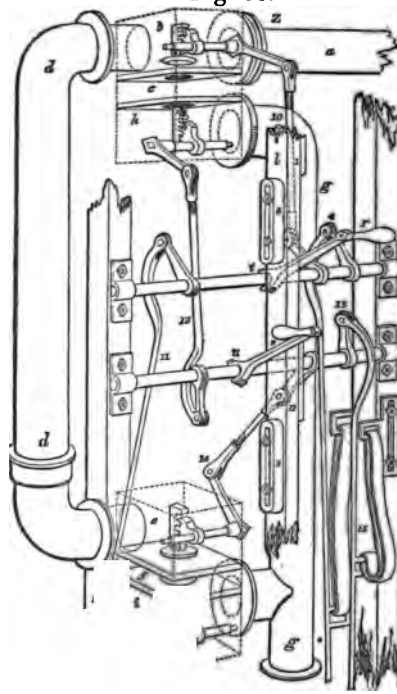
Fig. 84. Fig. 85.



valve; *h* the upper exhausting valve; *i* the lower exhausting valve; *c* the upper port of the cylinder; *f* the lower port. The seats of the exhausting valves *h* and *i* are inverted, so that these valves open when drawn downwards, while the steam-valves open when drawn upwards. Each valve has a toothed rack attached to it, which is acted on by a toothed sector, fixed on an axis, whose end passes through the valve-box, and carries an arm or handle by which it is moved as follows:—the arm or handle of the upper steam-valve is connected by the rod 10 with an arm fixed on the axis *t*, and the arm on the axis of the lower exhausting valve is also connected by the rod 11 with a similar arm fixed on the same axis *t*. The arms of the lower steam-valves and upper exhausting valves are in the same manner connected with arms on the axis *u*, by means of the rods 13, 14. These axes *t*, *u*, carry each a handle *tr*, *us*; and on these the plugs or chocks 1, 2, 3, 12, of the plug-rod *l* 12, act. When the plug-rod is descending, its chock 1 comes in contact with the handle *tr* of the axis *t*, and depressing it, turns round the axis *t*, so as to shut the upper steam-valve and the lower exhausting valve; and at the same instant its chock 3 comes in contact with the handle *us* of the lower axis *u*, and depressing it, opens the lower steam-valve and the upper exhausting valve. In the upward motion of the plug-tree, the position of the handles are reversed by the chocks 12, 2. The axis *t* carries a short lever 4, to the end of which there is a weight hung through the rod 4 4. When the valves connected with the axis *t* are opened, this weight keeps them open; but is prevented from opening them too far by the strap attached to the rod, as seen in the figure. The lower axis *u* has a similar apparatus,

15, 15, for the same purpose. It remains to notice how the exhausting valves are prevented from being opened by the pressure of the steam. The rods which connect the arms on the axes of the valves with the arms on the axes *t u*, it will be observed, are bent at one extremity in such a manner as that when the valves are shut, the connecting rods and the arms on the axes *t* and *u* fall into the same straight line, as is seen in the case of the upper exhausting valve in the figure. In this condition the arms of the axes *t* and *u* cannot act as levers in turning these axes round, and the valves are thus effectually locked un-

Fig. 86.



til released by the action of the chocks upon the handles *r s*.

Mr Murdoch's conical valve is represented in the next figures: fig. 87 a side view, and fig. 88 a front view.

Fig. 87.

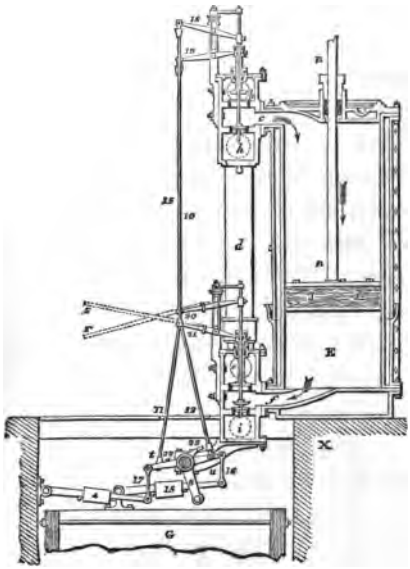
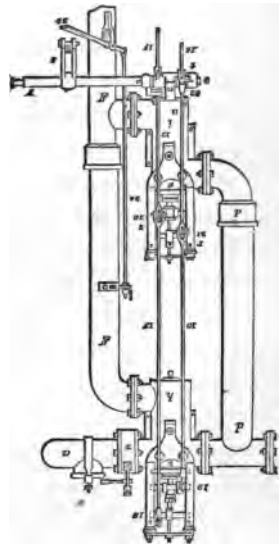


Fig. 88.



a d d are steam-pipes, and *g g g* eduction-pipes as merly; *c* being the upper port of the cylinder, and *f* the bottom port; *b* and *e* the top and bottom steam-valves, *h* and *i* the top and bottom eduction-valves. The steam-valves *b* and *e* are raised or lowered by hollow rods or tubes, through which the spindles or rods of the eduction-valves *h i* work freely without interference. A rod 10 joins the short levers 19, 20 of the valves *b*, *e*, together, and another rod 13 joins the levers of the valves 18 and 21 together; so that by inserting into sockets, formed on the ends of the levers 20 21, the bars *r s*, shown by dotted

lines, and by using them as lever handles, the upper steam and lower eduction valves are opened simultaneously by the handle *r*, and by the other lever *s* the lower steam and upper eduction valves are opened also simultaneously and alternately with the former. The rods 10 and 13 are connected by the rods 11 and 12, with an apparatus of levers and weights, acting through an axis at 22, by which the valves are retained in their seats.

The last valve which we shall describe is the crown-valve, or equilibrium-valve, which is in use on the Cornish engine, and has also been introduced into rotative engines by Mr Fairbairn, and Messrs Caird & Co., and which deserves to be better known than it is. Its value consists in effecting a large opening, and requiring little force to work it, while large valves of the common sort are heavy, or are so much pressed in one direction by the steam as to require great force to work them. The valve has been called the crown-valve, from the resemblance of its appearance to that of a diadem. Let there be conceived a chamber, fig. 89, out of which an aperture A leads into the cylinder, and into which a pipe S brings steam. The aperture A is surrounded by an upright ring or collar rising a few inches into the chamber, which ring is on all sides perforated by slits of considerable size, but closed at the top. The next figure, 90, represents the crown or cover of this valve, which is also a ring attached to a steel rod or spindle, by which it is raised or depressed. All round at top and bottom, the collar in the chamber and the crown-valve are ground, so as accurately to fit each other. The next diagram, fig. 91, represents the valve on its seat, and closed on all sides, so that no steam can find admittance; and fig. 92 represents it open or

raised up from its seat, with steam entering freely on every side.

Fig. 89.

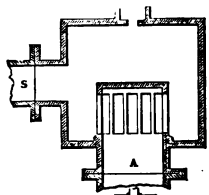


Fig 90.

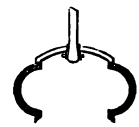


Fig.91.

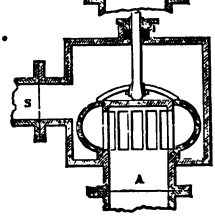
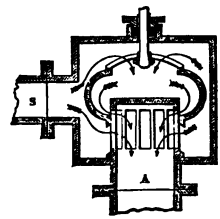


Fig.92.



These valves are arranged in a manner similar to the common conical valves, and work in the same way, four of them being used in a single engine, instead of four conical valves as in fig. 86. The following diagrams, figs. 93, 94, show the valves and valve-gear of a Cornish steam-engine, with the gear for working the valves either by the hand or with the pump-rod of the steam-engine. It is very perfect, and deserves the study of the intelligent engineer. The valves are equilibrium valves, such as we have already described. Although we cannot here enter into a detailed description of the mechanism, the engineer will at once understand it from the drawing.

In immediate connexion with the valves and passages of a steam-engine, which admit the steam on alternate sides of the piston to do its work, and afterwards discharge it, we may consider the means by which the engine is rendered automatic, or capable of performing its

Fig. 93.

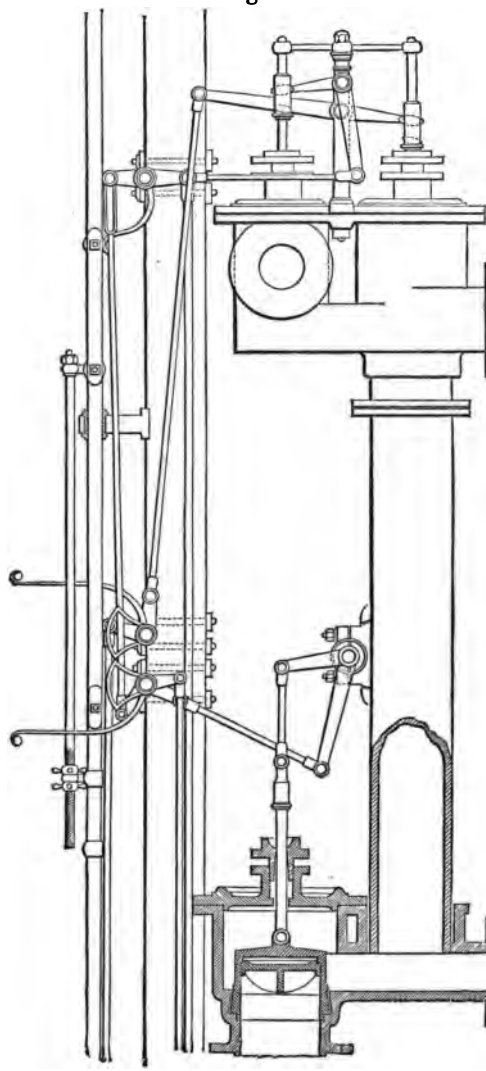
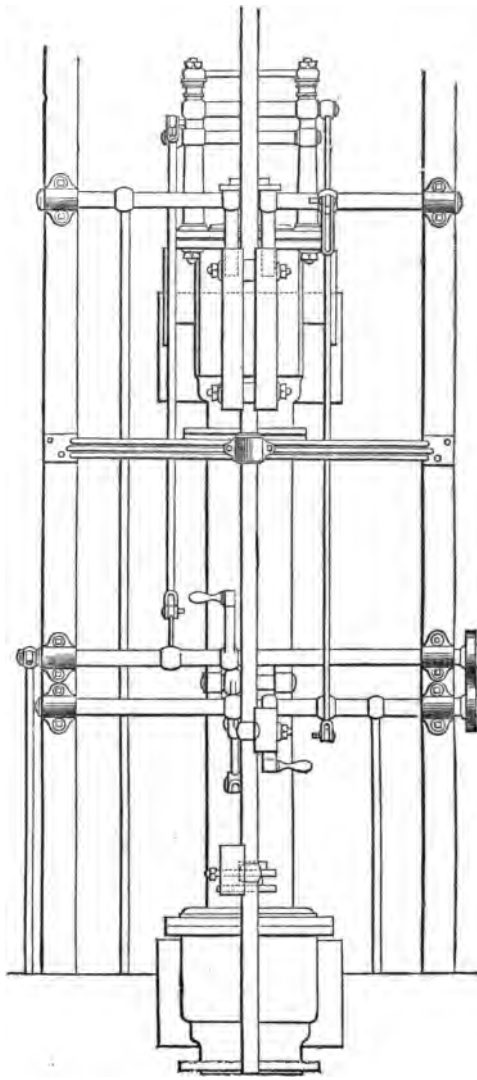
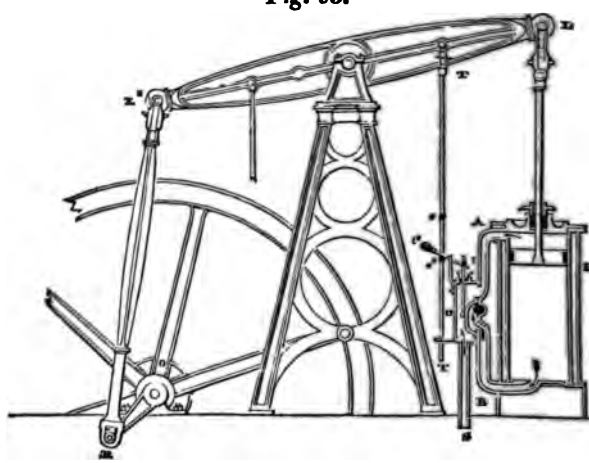


Fig. 94.



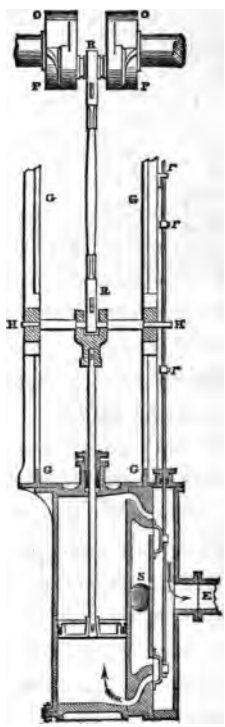
labour, in the most perfect manner, without the continual assistance of a man to open and shut its valves. There are two ways in which valves are worked by the steam-engine itself. The first of these is by the agency of some part of the engine that happens to move up and down, or perform a reciprocating motion, and the other is by the agency of some part of the engine which revolves. The following is a simple method, which we have seen applied to the short D-slide, already described. In figure 95, A B P is the cylinder, P the piston, acting on the end L, of a great lever L L^2, raising and depressing it alternately, while the other end L^2, united by a connecting rod L^2 R to the handle or crank of a large wheel, turns it round. The manner in which the steam-valves are moved is by the long vertical bar T T, suspended from the lever L L^2, so as to move up and down with it. This bar T T carries two projecting plugs of wood *s* s^2 upon it, which strike alternately up

Fig. 95.



and down the handle $l\ l^2$ at the bottom and top of the stroke, and so produce the reciprocating motion of the slide-valve D, and by admitting the steam on alternate sides of the piston, and discharging it at the opposite ports, produce the continuous motion of the engine. In the figure, the steam is represented in the act of forcing down the piston; but when the piston gets near the bottom, the plug s will have come in contact with the valve-rod $l\ l^2$, and will have forced it and the slide-valve D into the opposite position, and so permitted the steam, formerly above the piston, to pass into the open air, while the steam on the other side presses up the piston, so as to bring the plug s^2 in contact with the lever, pressing it up, and the valve D down into its first position, and so on alternately.

Fig.96.



This first plan of moving the valves by means of a plug-frame, rising and falling with the alternate strokes of the piston, has been principally adopted for pumping engines that have no revolving motion. We have, however, seen it adopted with advantage even in marine engines. It is noisy, as the sudden strokes of the prime mover produce an instant jerk; but it is effective, in so far as it at once opens the ports to their fullest extent, and so allows full

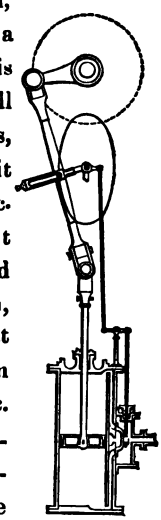
effect to the entering steam, and full clearance to that escaping. The form in which we have seen it adopted in marine engines is as follows. The piston was kept in its true position by moving along two guide bars G G, on which it rested, through a cross bar H H; O P and O P are the cranks of the revolving axis; R R is a rod connecting the piston-rod with the ends of the cranks which it turns round. The valve-rod *r r* is extended upwards as far as the piston-rod works, and two plugs *r r* are so placed by adjusting screws, as to admit of the rod being raised and depressed at the proper moment by a projecting part of the cross bar H, at the end of each upward and downward stroke.

A very beautiful method of working the valves of the steam-engine has been recently invented by Mr. Melling, the superintendent of locomotive engines on the Liverpool and Manchester railway, and applied with perfect success. It consists in deriving the motion of the valves neither from the rectilineal nor the circular motions of the machine, but from the connecting rod, one end of which rod moves round in the circle of the crank, while the other end performs a rectilineal, or a circular reciprocating motion. Before entering on the consideration of this motion, it may be well to attend to the curve which a point in the connecting rod describes.

The curve, Fig. 97, is manifestly a curve resembling the ellipse, although by no means a correct ellipse. It is an oval, one end of which is more oblate, and the other more elongated, depending on the length of the connecting rod, and deviating more and more from a true ellipse, as the connecting rod becomes shorter. In the centre of this oval, Mr. Melling places an axis, having a

projecting arm, and in the connecting rod there is placed a round projecting pin, which carries with it a radius arm from a fixed axis in the centre of the oval. This axis again carries another arm, or small crank, which is turned round with the axis, and is attached to the valve-rod, which it moves just as in the case of the eccentric. This motion has several good qualities. It is said to continue longer in perfectly good order than the common eccentric motion, and it is said to save steam. This last fact we are disposed to question. The motion exaggerates the properties of the eccentric.

Fig. 97.



One of the commonest of the many applications of the steam-engine is to produce the revolving motion of an axle and wheel, and in the second system of valve apparatus, by which the steam-engine is rendered automatic, the reciprocating motion of the steam-valves is derived from the continuous revolving motion of one of the shafts or wheels. Of the various methods in which this has been done, the following are some examples.

On the axis *o*, (at the bottom of the right side of fig. 98,) which is turned round by the rod LR so as to make one complete revolution during each alternate ascent and descent of the piston, and at the centre *o*, is placed a smaller axis, carrying round a cam or projection with it. A square frame $s^1\ s^2\ s^3\ s^4$ encloses this cam. As the axis turns round, the cam comes into such positions as to bear upon the bars $s^1\ s^2$ and $s^3\ s^4$ successively, and so pushes the frame towards the right and left alternately. *s e v* is a small crank,

Fig. 98.

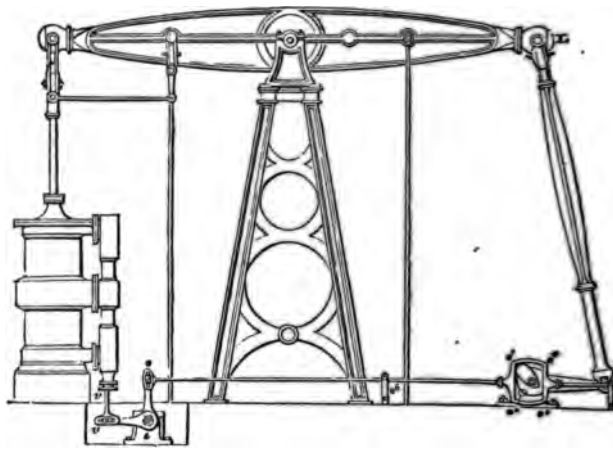
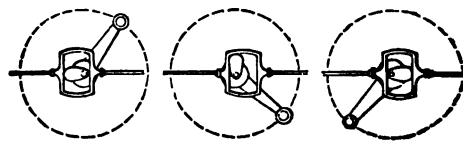


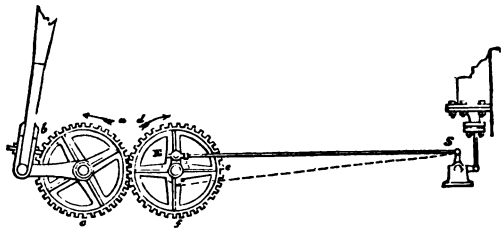
Fig. 99. Fig. 100. Fig. 101.



to which the motion of the frame is applied so as to make it move round its centre *e*, and so raise the point *v* and the valve rod *v v* up and down, giving the valve to which it is attached a reciprocating motion. The different positions into which the frame is forced by the cam are sketched in figs. 99, 100, 101.

Another form in which this motion has been given, is by connecting the large axle of the crank with a smaller one by toothed wheels. The principal or crank axis, fig. 102, carries round a wheel *a b c* whose teeth give motion to the equal wheel *d e f*. The point E is out

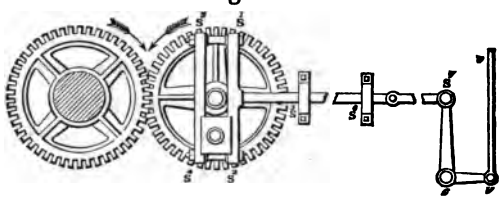
Fig. 102.



of the centre, and carries a small axis E, to which the crank is connected by the rod E *s*, so as to raise and depress the valve-rod. It is manifest, that during the revolution of the wheels *a b c* and *d e f*, the point E will be carried round a circle, and communicate alternate motion to the rod E *s*, equal in extent to the diameter of that circle. This circle must, therefore, be chosen of a diameter equal to the required motion or throw of the steam valves attached to the cylinder.

This motion has been modified into a very excellent and durable arrangement in the following form.

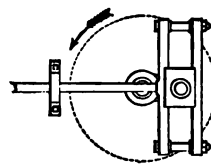
Fig. 103.



Here the toothed wheels are as in the former figure, and the eccentric pin or crank-pin is carried round by the inner one. On the crank-pin is a square brass nut or collar, made to fit exactly a space left between two parallel bars S^1 S^2 and S^3 S^4 that are kept *in situ* by means of nuts and screws at their extremities, and capable of adjustment. S^3 and S^4 are connected with the straight bar S^5 and S^6,

which works steadily through the collars S^5 and S^6, and from its end a connecting link S^6 and S^7 passes to work the crank and valve-rod S *c v*. This apparatus we have seen work well without repair for a long period. It was executed by the Messrs Carmichael of Dundee. Figs. 104, 105, 106, show the apparatus in three other positions.

Fig. 104.



Another mode of producing the motion of the valves is by a projection in the great axis of the engine itself. A rigid circular hoop S encloses the axle as in figs. 107, 108, 109, 110. It is evident that if the projection E be just equal to the radius of the hoop, the axle will revolve without producing motion in the hoop; but, if on the contrary, the axle and its projection be equal to the diameter of the hoop, as in the figs. 107, 108, 109, 110, it is apparent that the projection or cam, in passing round, must push the hoop in alternate directions.

Fig. 105.

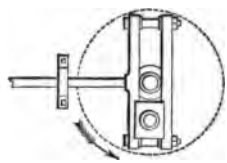


Fig. 106.

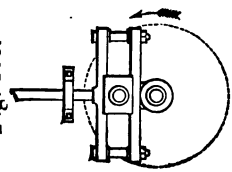
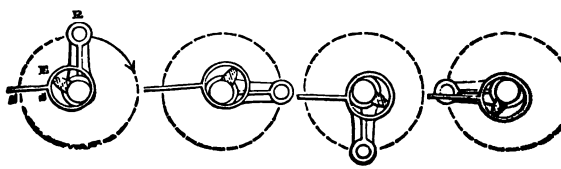
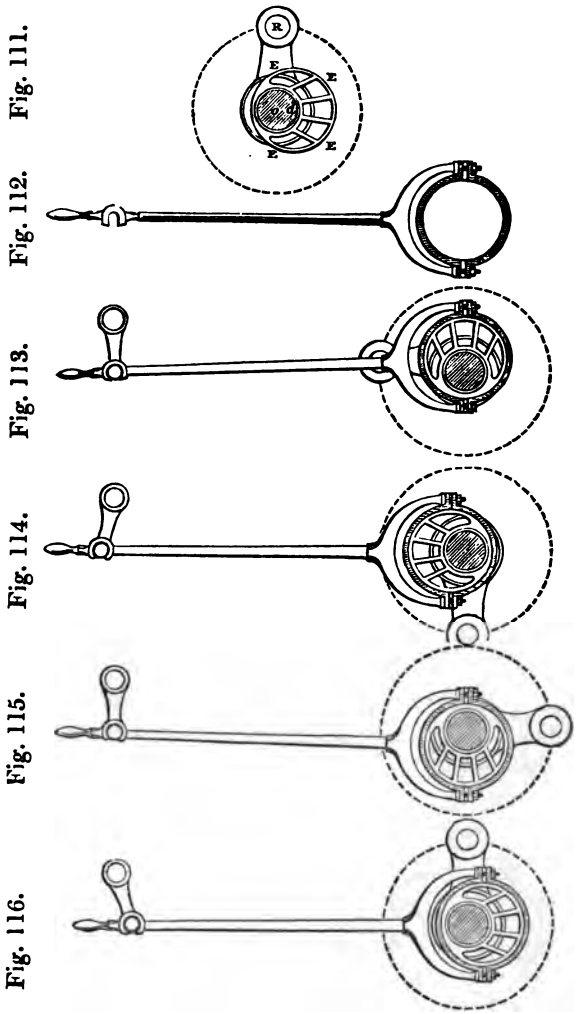


Fig. 107. Fig. 108. Fig. 109. Fig. 110.



But that modification of this principle, which is in by far the most general use, is in the form called "the

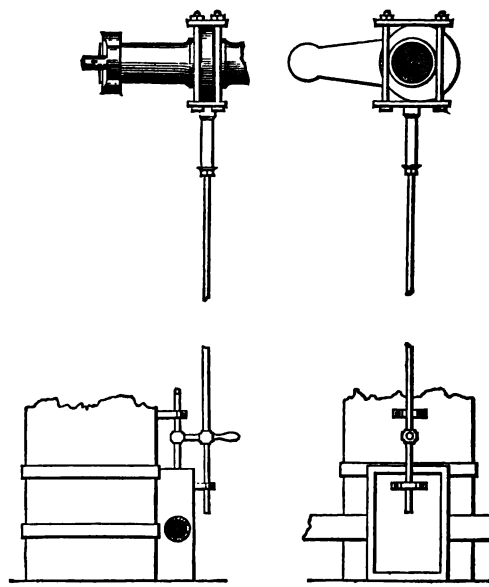


eccentric." The eccentric is a circular disc, or ring of metal, placed upon the shaft or axis, turned by the crank.

O, fig. 111, is the centre of the shaft or axis, to which revolution is given by the crank R of the steam-engine. On this axis the circular disc E E E is placed, but eccentric to it, so that its centre *d* moves round the axis. The distance of the centre *d* of the disc from the centre O of the axis, is called the eccentricity, and it is equal to half the throw or range of the motion of the valves to be moved by the eccentric. The rod, fig. 112, is called the eccentric rod, and is attached to a hoop or circle that exactly fits the eccentric disc. The various positions which the eccentric will take during the revolution of the engine, is shown in the succeeding figures.

We have used the common eccentric in a much simpler

Fig. 117. Fig. 118.



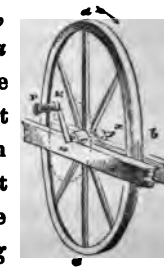
form than that generally adopted, by placing it immediately over the valve which it moves. In engines which require compactness and simplicity, this way is useful. and is valuable where the axis of rotation is immediately over the valves, as in figs. 117. 118.

In these the valve-rod branches out into four portions; a flat brass plate is inserted at their separation, another at the summit unites them. The eccentric disc works between the side forks of the rod, and bears against its top and bottom plates, as seen in fig. 117. The other forks of the rod are made, in width, equal to the diameter of the axle, which thus prevents the rod from deviating from the vertical position, as seen in fig. 118; a handle is added to work by hand, and the reversing process is performed as usual.

The Crank.—One of the most important appendages of the steam-engine is the crank, by means of which the force of steam, although at first producing motion only upwards and downwards in the right line of the axis of the cylinder, is nevertheless rendered capable of exerting that force equally well in a circular direction. When the steam-engine is only employed for some such purpose as pumping up water, no crank is necessary, but as some of the most usual and valuable applications of the steam-engine are those where it turns wheels of mills, cotton machinery, steam-vessels, or locomotive engines, the crank, by which this is accomplished in an admirable and simple manner, which has susperseded every other plan of transmission, is entitled to very minute consideration.

A crank is an elementary machine which has been used from the earliest times for the purpose of converting a revolving into a rectilineal motion, or the reverse. It is figured in the old machines of the Egyptians, Chinese,

Greeks, and Romans, and in water machinery it has been in common use from the time of Ctesebius. Fig. 119.



A crank is merely a handle to a wheel, by which it may be turned round. Let *a x* be an axis of a wheel *b c d*, *a* R P the usual bent (or crooked) handle, by which it is turned round by the man, whose arm first pushes it from him, and then draws it towards him, and so continually turns the wheel round, then the part *a* R radiating from the centre, is called the crank, the axis *a x* is called the crank-axle, and the straight part PR is called the crank-pin.

Now imagine, instead of a man's arm, a rigid metallic connecting-rod, and instead of the strength of his body, conceive the force of steam to be applied, through a cylinder, piston, and piston-rod, to the crank by means of the connecting rod, and the steam will produce the revolution of the wheel by means of the crank, axle, and pin, as in the figure, A the cylinder, *p* the piston-rod, *p* R the connecting rod, R the crank, and *a x* the axis.

Fig. 120.

On examining, in detail, the action of the crank, it is to be observed that the force exerted by the steam is neither continuous in direction nor in action. If the steam be admitted first below the piston, it forces it to the top of the cylinder; it is then cut off preparatory to its being admitted above the piston; and in the interval

it has no motive action. When admitted above the piston, it forces it to the bottom of the cylinder; and again there is a cessation in its action during the change in the position of the valve. Now it is evident that this recurring cessation of action between the alternating impulses, would prevent the production of continuous revolution in the wheel, but for the power of the wheel itself of continuing the motion, by what is termed the momentum of its mass. When the steam, during a stroke of the machine, is acting most powerfully on the piston, part of its power is absorbed in giving motion to the wheel; and when, at the end of the stroke, it ceases for a time to act, the wheel gives out the power which it had absorbed, and continues its motion until the next stroke gives it a fresh accession of power. A wheel of this kind, when attached to an axle for the purpose of equalizing motion, is termed a fly-wheel; and to obtain the full benefit of its equalizing power, it is made of large diameter, that its rim may move rapidly, and it is made of great weight, being formed either of lead or iron, that it may acquire momentum to render the motion as uniform as possible.

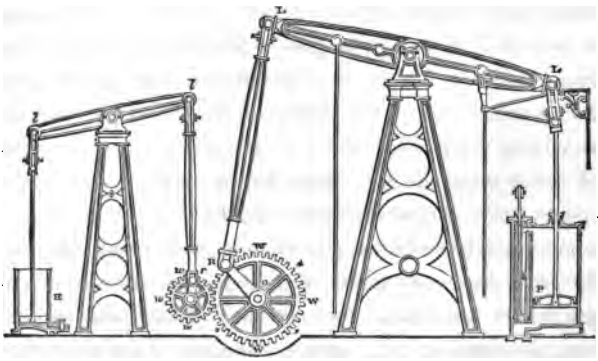
Still, however, it must be remembered, that the equalization of the motion produced by the fly-wheel is partial, not perfect. Matter only takes up or gives out force when it changes from one velocity to a different one. If, therefore, the fly-wheel take up into itself the accession of force of the steam at one part of the stroke, it does so by slightly accelerating its motion; and if it give out force during the cessation of the stroke, it is by slightly reducing its own velocity in so doing. The approximation to perfect uniformity in the motion of the steam-engine, will be proportioned to the mass of matter in the rim

of the wheel and to the square of the wheel's velocity. Although, therefore, the fly-wheel improves the action of the crank, so as to make it perfectly adapted to all ordinary purposes, still the effect is not so equable as the power of a water-wheel where *extreme* delicacy is required. In all ordinary cases it is sufficiently uniform.

The following substitute for a fly-wheel was suggested and constructed by Mr Buckle of Soho, for Mr Lucy of Birmingham, and is an admirable and elegant substitute or auxiliary; so as to be, for even the most delicate operations, practically perfect. Mr Lucy had constructed at Birmingham a flour mill driven by steam; and it had been his object to obtain perfection without any limitation of expense. He had got one of Bolton and Watt's best steam-engines, and yet he found that his mill neither produced such perfect flour nor moved so smoothly as mills driven by water. On the contrary, it was found that the irregularity of the motion produced a larger quantity of coarse than of fine flour, at a mercantile loss to the owner; and it was likewise found that the irregular propulsion *a tergo* interfering with the uniform motion, towards which the millstones tended by their own momentum, produced a clanging reciprocation along the whole line of toothed gearing, which was most injurious, and rapidly destructive to the toothed wheels. When we visited the spot in 1838, the ruins of former wheels, most unequally worn and totally destroyed, were strewed about the yard. The usual plan of increasing the weight of the fly-wheel was resorted to without success; and Mr Lucy applied to Mr Buckle to propose a remedy for the evil. This remedy Mr Buckle found in the very simple contrivance of a pneumatic pump. In the mint at Soho a

pneumatic pump had been introduced by Mr Watt, for the purpose of producing a reaction, on the principle of the experiments of Otto Guericke, which we have already described. The force of the steam-engine was made to draw up a piston from the bottom of a cylinder, leaving a vacuum below it. Into this vacuum the piston was again carried down, after the action of the steam had ceased, by the whole force of the atmosphere, amounting to about 15 lbs. on every inch of its surface. Thus the atmosphere was rendered a reservoir of power, the power being first of all taken up by forming the vacuum, and again given

Fig. 121.



out by the atmosphere pressing the piston down into the vacuum.

The following is the arrangement by which Mr Buckle accomplished the object which he had in view. P, fig. 121, being the usual piston and cylinder of the steam-engine, L L the usual lever, L R the connecting rod, R O the crank, and R W W W a toothed wheel carried round by the crank, as usual in the steam-engine: there is added *r w w* a smaller wheel of half the number of the teeth of the other, so that during a semi-revolution of the small

wheel, the large one performs a quarter of a revolution; *l l* is a second lever to which there is attached a piston-rod L H, carrying a piston from top to bottom of an open cylinder H. When the piston is at the bottom of the cylinder H, the crank R is near the point 1 in the figure. While the crank passes from 1 to 2, it is raising the piston in the pump and against the pressure of the atmosphere, the steam exerting its greatest force; but when the crank reaches point 2, the little wheel *w w r* is at the bottom of its circuit, the piston in the pump is at the top; and now the pressure of the atmosphere carries the piston down into H, turning the little wheel *r w w* along with it, and propelling the large wheel and crank from 2 to 3, through that part of the stroke where there is a cessation of the action of the steam: then again from 3 to 4 the excess of the power of the steam is employed in raising the pump piston; while from 4 to 1 the piston of the pump, carried down by atmospheric pressure, brings round the mechanism once more to the point 1.

So perfect was the action of this mechanism that the fly-wheel had been wholly removed, and the engine and the whole mill-work were moving in the most smooth and effective manner. It was found that the change enabled them to give all the grinding stones a greater velocity than formerly, so that the quantity ground was greater, in the proportion of 56 to 52, and the quantity of the finest or first flour, from the same wheat was likewise much increased; so that, both by quantity and quality, the owner of that mill was now able to "command the market." The same motion has subsequently been applied to cotton-mills with perfect success; the quality and the quantity of yarn produced being much improved.

From the circumstance already noticed, that at one point the steam possesses no power of giving revolution to the crank, it has been imagined that some considerable loss of the power of the steam takes place during the transmission of its moving force through the crank. This is a grave error, and it has produced other errors, which we shall consider in our chapter on rotatory steam-engines.

Fig. 122.

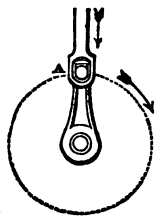


Fig. 123.

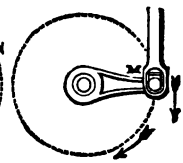


Fig. 124.

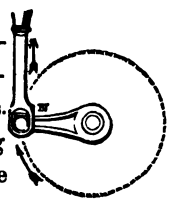
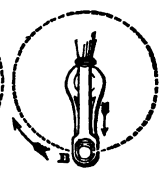


Fig. 125.



Figs. 122 to 125 represent the crank in different positions. In figs. 122, 125, the connecting rod and crank are in the same straight line, technically called the position "on the centre," or passing the line of centres, in which the action of the crank neither tends to produce motion in the one direction nor the other. Again, at M and N, figs. 123, 124, where the crank is represented as acted upon at right angles by the connecting rod, it is plain that the whole force transferred through the rod is acting to produce the effective motion of the crank; while in the intermediate positions there are two effects produced, one acting on the centre of the crank, and another acting to give it revolution. For the purpose of examining the proportion of these forces to each other, we may use the two following diagrams:

Fig. 126.

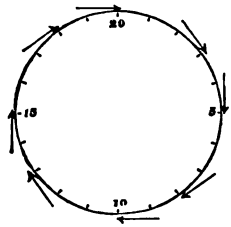


Fig. 127.

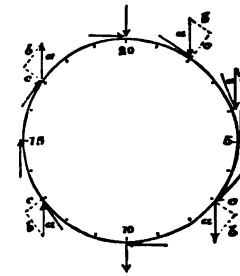


Fig. 126 represents the circle of the crank, the arrows showing the direction in which the crank-rod would require to act, in order that all its force should be undivided, and produce alone the single effect of causing revolution. Fig. 127 indicates the deviation which the actual motion of the crank exhibits from this hypothetical condition. The arrow *a* indicates the direction of the action of the connecting rod, which at divisions 10 and 20 is acting only towards the centre of the circle with no effect in producing revolution. At divisions 5 and 15, the whole effect takes place in producing revolution only. Through the first half of the circle the pressure of the rod acts wholly downwards, and through the latter half of the stroke wholly upwards. The circumference of the circle being divided into 20 equal parts, the analysis of the force is given in the figure at several of these points. At the second division, *a* represents the direction of action of the crank-rod, *b* is parallel to the direction of the circumference (or tangent) of the circle at that point, while the line *c* is directed to the centre; *a* indicating the direction of the whole force of the connecting rod, *b* representing the effect produced in the direction of the tangent to turn it round, and *c* the

effect of the force of the connecting-rod acting to produce pressure on the centre of the crank; but as the centre of the crank is fixed and prevented from moving, none of the moving power of the crank is given out in producing motion towards the centre, but only in producing motion in the circumference. At the fourth division of the circumference, it may be observed, that the effect of the connecting rod is differently distributed. The whole force *a* is now more nearly in the direction of *b*, and *c* is comparatively small; showing that as we approach the end of the first quarter's revolution, the force of the connecting rod is producing much less pressure in the centre of the crank, and pressing in a higher proportion in the direction of the revolving effect, until at last the connecting rod being at right angles to the crank, its whole pressure acting to turn round the crank, none of it is directed towards the centre. After passing the quadrantal point 5, the crank-rod still presses downwards, as shown by the arrow *a* at point 7; but, of its two effective pressures, one represented by *b* still acts in turning round the crank, while another represented by *c*, instead of acting towards the centre, as in the upper quadrant, now produces a pressure which would draw the crank away from the centre; but as the crank is fixed, none of the motive power is employed in producing any motion of the crank away from its centre. Similar alternating effects are produced through the other quadrants; so that, while the pressure of the steam, acting through the connecting rod upon the extremity of the crank, is divided into two effects, one of these is prevented from expending the moving force of the engine by the fixedness of the crank centre, and the whole motive power

is given out only at the circumference of the crank circle in turning it round, but in a proportion of pressure that is continually varying from 0 to a maximum, and from a maximum to 0, through every successive quadrant of the circle. The amount of the variation is shown in the following table:—

Points in the figure.	Pressure in direction of revolution.
0 and at 20	0.00
1 19	30.90
2..... 18	58.78
3 17	80.90
4 16	95.11
5 15	100.00
6 14	95.11
7 13	80.90
8 12	58.78
9 11	30.90
10 10	0.00

Mean pressure 63.11

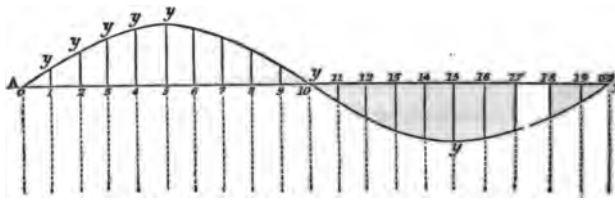
The mean pressure on the crank being in the table about 63 pounds, taken on an average of the whole circumference of the circle, the pressure varies from 36 pounds above the mean, to 63 pounds below it. The total pressure of the steam in the cylinder, forces the connecting rod up and down through a space equal, each time, to the diameter of the circle, while the connecting rod carries the crank through a space which is equal to the whole circumference; and as the circumference of a circle bears to twice its diameter an approximate ratio of 100 to 63, it follows, that the pressures on the crank and piston are

inversely as the spaces through which they move: the motive power of steam in the cylinder being 100 lbs. moved through a space of 63, and the motive power given out in the crank, being a mean of about 63 lbs. moved through the circumference of a circle which is represented by 100, so that the motive power is in the one case 100 lbs. $\times$ 63 = 6300 lbs., and in the other case 63 lbs. $\times$ 100 = 6300 lbs.

The crank is merely one beautiful exemplification of the great dynamical principle, which includes in it the law of operation of all the elements of machinery, "that in uniform motions the quantities of motive power, or *vis viva*, may be transferred from one point to another, through every variety of direction, velocity, and intensity, by material mechanism, without being thereby altered in quantity, except in so far as friction and imperfect rigidity may diminish its amount by a certain percentage, which diminution it is the aim of all perfect construction and design, in the practical application of machinery, to reduce to the smallest possible amount." To render uniform the effective pressure given out by the crank, is the object of the fly-wheel, and of the pneumatic pump of Mr Buckle. For the same purpose many other expedients have been devised; and the following explanation is intended to facilitate the comprehension of the nature and value of these expedients.

The variation of pressure on the crank of a steam-engine, may be conveniently represented by curves. Let the circumference of the circle described by the crank be represented by the straight line A X, fig. 128, and divided into any number of equal parts; let straight lines y^1 y^2 y^3 &c., be drawn to represent the amount of

Fig. 128.

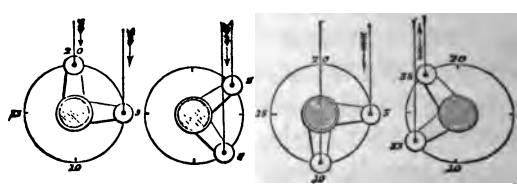


.0.00 30.90 58.78 80.90 95.11 100.00 95.11 80.90 58.78 30.90 0.00 30.90 58.78 80.90 95.11 100.00 95.11 80.90 58.78 30.90 0.00

pressure converted into the direction of the motion of the crank, according to the line *b* in fig. 127, being the amounts represented in the line of figures, then the curved line A *y y y x* passing through the summit of all these lines will represent the variation in the power of the crank at each instant of time, each ordinate y^1 y^2 y^3 being the pressure, and the area of the whole figure will represent the whole motive power, having a maximum of y^5 and y^{15}, and a point of change of direction from pressure one way to pressure the opposite way at y^{10}.

Now one method of equalizing the rotative pressure on the crank has been proposed, and is very generally adopted, viz. to make two steam-engines act on the same axis by means of two cranks at right angles to each other, so that when the one ceases to exert force, the other may be at its point of greatest force.

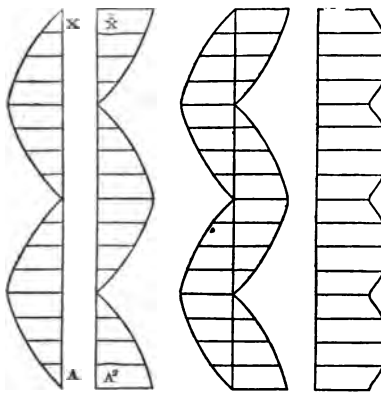
129. 130. 131. 132.



Thus in the figures 129 to 132 two cranks are represented as coming from two cylinders, and attached to the same axis, so that when the one of them is at 0, the other is at 5, when the first is at 5 the second is at 10, and so on; so that while either is on the line of cessation of force, the other is at the point of maximum.

The joint effect of two such cranks may be represented by curves in the following way:—

133. 134. 135. 136.



First.	Second.	Sum.
00.000	100.000	100.000
38.268	92.388	131.656
70.710	70.710	141.420
92.388	38.268	131.656
100.000	00.000	100.000
92.388	38.268	131.656
70.710	70.710	141.420
38.268	92.388	131.656
00.000	100.000	100.000
38.268	92 388	131.656
70.710	70.710	141.420
92.388	38.268	131.656
100.000	00.000	100.000
92.388	38.268	131.656
70.710	70.710	141.420
38.268	92.388	131.656
00.000	100.000	100.000

Let the circumference of each crank circle be represented by the lines A X and AX as formerly, each semicircumference being divided into eight parts, and let the pressure be calculated from a table of sines, where each will be found as the sine of the arch of the circumference to which it corresponds; the numbers thus obtained being arranged on the right of the figures, so as to obtain by the two curves the representation of the varying quantity of force, but without regarding the reversion of direction. If now we place these curves together, as in fig. 135 their whole ordinates taken across from the

one curve to the other, will truly represent the amount of the sum of the forces and its variation; and if we place all these ordinates from a fourth axis, we shall have truly represented, by the new curve (fig. 136) the variations of the sum of the forces of the two cranks. The figures in the third column represent the sums of the ordinates, in which it is shown that the maximum is 41 per cent greater than the minimum pressure, even when two cylinders are made to act on cranks at right angles to each other.

The whole of this calculation is summed up in the following formula:

Let r be the radius of each crank,

x the effective leverage of one,

$\therefore \sqrt{r^2-x^2}$ is the effective leverage of the other,

and $x + \sqrt{r^2-x^2}$ the sum of the pressures:

from which we obtain, by differentiating

$x = \sqrt{r^2-x^2}$ in the case of a maximum,

and when $x = 0$, the sum $x + \sqrt{r^2-x^2}$ becomes $= r$

or when $\sqrt{r^2-x^2} = 0$, $x + \sqrt{r^2-x^2}$ becomes $= r$

and when $x = \sqrt{r^2-x^2}$, $x + \sqrt{r^2-x^2}$ becomes $= 2r$

$\sqrt{2}\,r.$

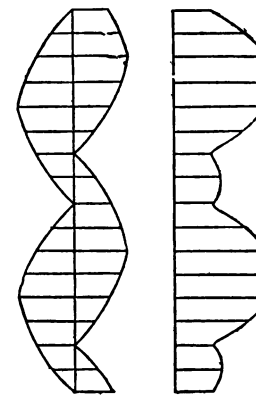
$= 1.411.$

Hence the point of greatest pressure is at 45° from the minimum and the minimum sums at the termination of each quadrant, the maximum being to the minimum as the square root of 2 to unity.

It is obvious then, in conclusion, that with two engines the variation above the mean, amounts to about 126—141=15 in 126, or about eleven per cent, and that the decrease below the mean amounts to twenty per cent.

It is a matter of some difficulty to decide at what angle the cranks should be placed in a double engine, so as to give the best effect. If we place them at a greater angle than 90° apart, the minima become small, and the maxima, however, are by no means sudden. If we place them at a less angle, the maxima become excessive; and although the minima be larger, the maxima are also larger. The following diagrams, 137, 138, show the effect of these two methods.

Figs. 137. 138.

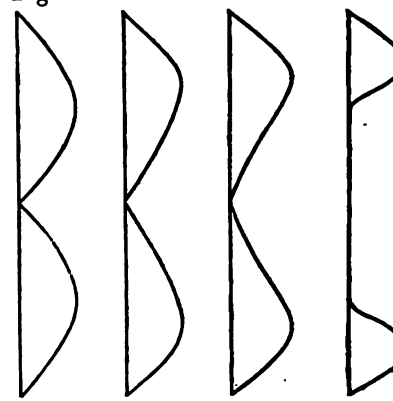


When a lever intervenes between the crank-rod and the piston-rod, new irregularities are introduced. The variation in the direction of the connecting link, and in the position of the lever-ends from a straight line, introduces modifications of these effects of a serious nature, but not of a large amount. It is worthy the attention of practical men to consider these variations, and the manner in which they affect the uniformity of the pressure. They affect it by way of increase at the beginning and end of the stroke. By proper arrangements these very obliquities may be rendered very considerable improvements in the working of the engine. It should also be observed that the stroke of the piston and crank will not remain of the same length.

The agency of the crank in transmitting a force parallel to the piston-rod has been represented by the curve of sines, as in fig. 139. But if we represent in a similar

way the pressures produced by the obliquity of the crank-rod, we shall find the form become that given in the following figures. Fig. 140 represents the variation of pressure with a crank-rod of four times the length of the crank, fig. 141 with a crank-rod of double the length of the crank, and fig. 142 with a crank-rod equal to the length of the crank.

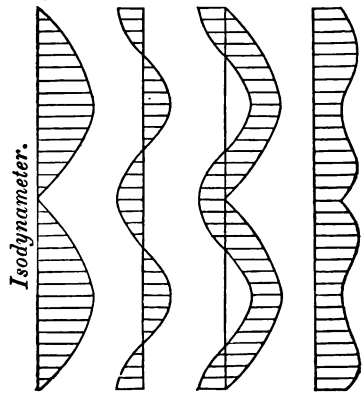
Figs. 139. 140. 141. 142.



It is obvious, that with the shortening of the crank-rod, the irregularity of the motion becomes very great. Two maxima rapidly succeed each other, and these are wide apart from the next pair. Thus two violent pressures succeed at a short interval, and a long pause intervenes, when the force is very small.

By the same system of curves we may proceed to examine the pneumatic equalizer of Mr Buckle. Let the rotative pressure of the crank be again represented, as formerly, by the curve in fig. 143. And let the rotative pressure of the pneumatic crank of the equalizer be represented by the curve in fig. 144, lying on alternate sides of the axis, so as to show the alternate coincidence with, or opposition to, the action of the steam-crank. Then if we place the two axes as in fig. 145, the lines betweeen the two curves will represent the sums of the

Figs. 143. 144. 145. 146.



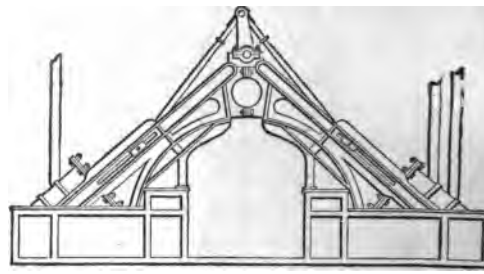
0.000	50.000	50.000
19.509	46.194	55.703
38.268	35.345	73.623
55.555	19.134	74.686
70.710	00.000	70.710
83.147	19.134	64.013
92.388	35.355	57.033
98.078	46.194	51.864
100.000	50.000	50.000

pressures; and if we set off these intercepted parts in a third curve, we shall get the line representing the variation of the resulting force, corresponding to the sums and differences of the former ordinates. The values of these are given in columns of figures on the right through one quadrant. The mean value 63 is in this case exceeded by 19 per cent, and is receded from below by nearly 20 per cent. The deviation from the mean pressure is not, therefore, greater than 20 per cent, and the equalization produced by Mr Buckle's pneumatic equalizer is as efficient as a pair of engines, and much less complicated and expensive.

Still, however, it is to be noticed, that as there is a variation of force amounting to about 20 per cent above or below the mean, with a pair of engines as well as with the pneumatic reservoir of power, it is obvious that the combination of a fly-wheel with either of these systems of arrangement, would be required to obtain the

nearest possible approximation to uniformity in cases of delicacy.

Fig. 147.



Instead of using two cranks for the purpose of applying the force of two steam-engines to the same axis of revolution, two engines have been used with their cylinders laid at right angles to each other, and having their connecting rods applied to the same crank. For an engine of this kind, fig. 147, Mr. Brunel obtained a patent; and we have seen his machine working in a satisfactory manner. An arrangement of a similar description has also been introduced in steam-boats by M. Cave of Paris.

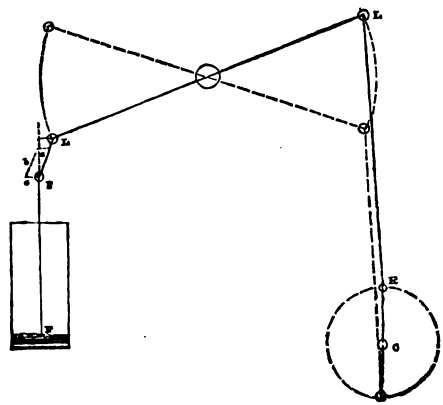
Of the Connecting Rod and Parallel Motion.—In considering the agency of the crank in modifying the force and velocity of steam, so as to connect its direction and distribute its force in the manner required to produce a rotative motion in the machinery, from the original reciprocating motion of the piston in the cylinder, we have hitherto avoided the introduction of another important element, by which a further variation of force and of motion is produced. The connecting rod is a rigid bar of

metal which conveys the motion of the piston from the piston-rod to the crank either immediately or through the interposition of the lever or beam; and as the connecting rod, in doing so, takes various directions different from those either of the piston-rod or of the crank, there is an obliquity of pressure produced at both extremities of the connecting rod, which gives rise to a variation of force and of direction, which must be practically provided for, and carefully appreciated in quantity, in so far as it may affect the ultimate operation of the machine.

There are two ways in which the motion of the piston-rod is most commonly transferred to the crank; either immediately through the connecting rod, as in fig.

Fig. 148.

Fig. 149.



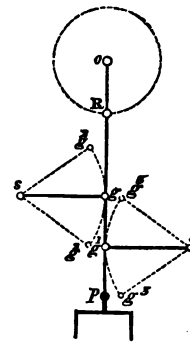
148, or through the medium of the great lever, as in fig. 149; both ends of the great lever describing circles

around its middle fulcrum as a centre, and the head of the piston-rod being connected with the one end of the lever by means of an iron strap or connecting link. From inspection of the figure, it becomes plain that the connecting rod or link, is never, except at two points, in the same straight line with the piston-rod, so as to propagate its unmodified force to the crank, but that in these oblique positions it would produce a lateral motion in the end of the piston-rod which would not only be a waste of power in producing motion in a place where it is useless, but would have the effect of continually bending the piston-rod in opposite sides so as either to break it, or materially to impair its working. In the first of these figures, P*p* being the direction of the piston-rod, *p* R that of the crank, the force in the piston-rod in the direction *p a* becomes resolved into two parts *p* R and *p e*, *p* R being effective in the direction of the crank-rod, and *p c* tending only to give lateral motion to the piston-rod, or else to bend it, or break it across. And so also in the second figure there is a similar separation of pressure.

To prevent these lateral pressures from wasting the power of the steam, by producing lateral, useless, or injurious motions, is the object of a series of contrivances called parallel motions, or parallel guides. The most notable of these we owe to Mr Watt.

Let it be supposed that we desire to prevent the top of the piston-rod *p*, fig. 150, from being moved by the obliquity of the connecting rod *p* R, either towards the right or the left, then it is accomplished in the following way. A fixed support, *s*, is found on one side of the piston-rod; and another on the other, s^2, at equal distances from it,

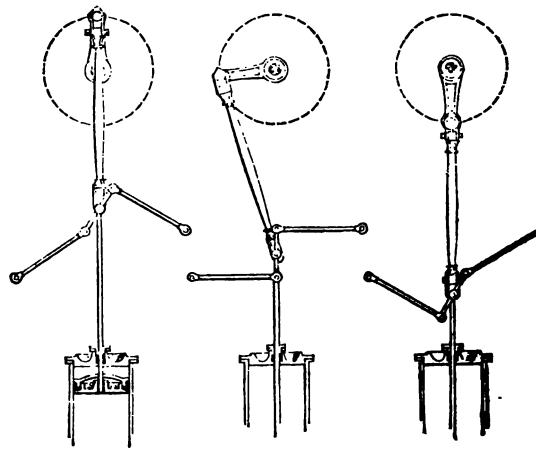
Fig. 150.



and two parallel bars $g\ s$ and $g^1\ s^1$ are placed between the piston-rod and these points, so that it may be steadied between them. These parallel bars are made so as to revolve freely round the points $s\ s^1$ as centres, each of the ends $g\ g^1$ describing the circles $g\ g^2$, $g^1\ g^3$, from which it is evident that if these rods were directly attached to the piston-rod at g and g^1, they should have the effect of keeping the point p in the straight line $o\ g\ g^1\ p$. As these bars $s\ g$ and $s\ g^1$ must describe circles round s and s^1, they would, in the positions $s\ g^2\ s^1\ g^3$, deviate altogether from the straight line of the piston-rod; but as the one will act nearly as much in the one direction as the other in the opposite, it occurred to Mr Watt that, by connecting their extremities with a link, $g\ g^1$, and attaching the piston-rod, not to the ends of the guide-bars, but to the middle of this link, the point p might be prevented from deviating to any appreciable extent from the straight line. This is accordingly produced in a very simple way. The following figures, 151, 152, 153, show the effect of these links in various positions.

This elegant and simple contrivance is not, however, absolutely perfect; and, in accurate workmanship, and on a larger scale, great allowance requires to be made for its errors, or it will produce very many serious derangements of the machinery to which it is applied. By this arrangement the point p is not kept perfectly in a straight line, but is, on the contrary, compelled to deviate from it

Fig. 151. Fig. 152. Fig. 153.



so as to describe a looped curve. The nature of this deviation will become very evident if we suppose the parallel motion to be altogether detached from the piston-rod, and the motion of the parallel bar and link carried to its extreme, as in the following figures, 154, 155. A pencil being used to trace the motion of the middle point, *p* will describe, not a straight line, but the curve *p x y*. When we carry the rods up to the position represented in the first of the following figures, where the bar *g s* comes into the straight line with the link *g g*, the point *p* deviates from the straight line by a quantity equal to p^1, and this is reversed in the opposite extreme. In the next figure the deviation is much greater when the link *g g* comes into the same line with the other bar *g s*, and is also reversed in the position at the bottom of the figure. By the time the links have been returned to

their primitive position, they have described the curve *x p y*.

Fig. 154.

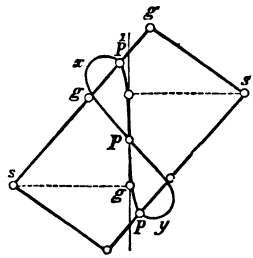
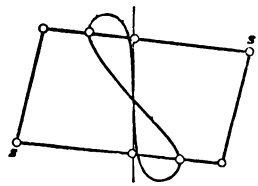


Fig. 155.



It is important to diminish the amount of this deviation, which increases more rapidly than the square of the length of the stroke. Having ascertained the amount of greatest deviation at the end of the stroke, and also the amount at $\frac{1}{8}$th part of the stroke from the middle, bring the centres *s* and *s* each nearer to the other by a quantity equal to the deviation at the said 8th part, and the amount of the greatest deviation will now be reduced to less than one quarter of its former amount: the curve will now become a line of the sixth (eighth?) order.

The parallel motion of one point having thus been secured, it is easy to transfer it to any other point. This is most commonly done by a jointed parallelogram. Thus, to transfer it to a point in connexion with *s g* prolonged to *t*, (figs. 156 to 158) take a second link *t q*, equal to *g g*, and a second bar, called the parallel bar *g q*, equal to *g t*, the corner *q* of the parallelogram will give a motion *t q*, similar to *p*. Figs. 159, 160, show the parallel motion transferred to a point still farther from the original point.

Fig. 156.

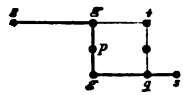


Fig. 157.

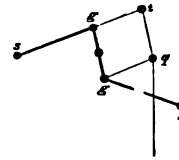


Fig. 158.

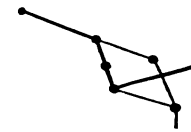


Fig. 159.

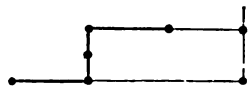
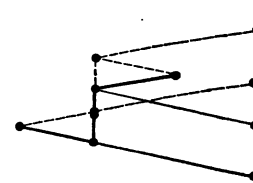


Fig. 160.



Another form of Mr Watt's invention consists in placing two bars in the same direction, with such a difference in their length, that the excess of the continuance of the one above the other may afford the means of compensation. Suppose that the point p, fig. 161, is to be guided to move in the straight line $p\ g\ g'$; $s\ s'$ are points on the same side of the required direction of motion, and $s\ g$ $s'\ g'$ are the differential bars connected by a link $g'\ g$,

Fig. 161.

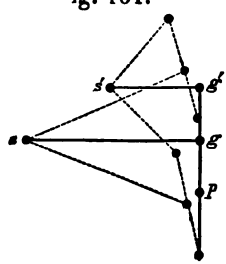
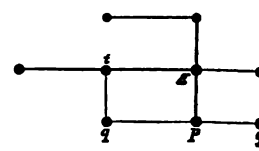


Fig. 162.



which is prolonged to *p*. The dotted lines of the figure show the bars in different positions. The line described by the point *p* is not a straight line, but a curve, like figs. 154, 155. The motion of the point *p* may be transferred to a distance, as in the former instance, by a jointed parallelogram *g p t q*, fig. 162. All these parallel motions may be inverted, and indeed generally are inverted in steam-boat engines. For practical examples of them, the reader may consult the plates.

All these motions are imperfect; that is to say, the motion of the end of the piston-rod does not take place in a perfectly straight line, but possesses high curvature. Various plans have, from time to time, been adopted for the purpose of remedying the evil. In American steam-engines Watt's parallel motion has been to a great extent abandoned, because in them long strokes and long cranks are preferred; and in such cases the deviations of the point *p*, that is to say, of the piston-rod, from a straight line, become excessive. Watt and his assistants and followers were perfectly aware of this, and hence were led to construct beams, and connecting rods, and parallel motions, of *very great length*, so as to diminish the evil as far as possible. This has, of course, the effect of rendering the whole engine both bulky and expensive, and is, therefore, in many cases inexpedient.

The American engineers, therefore, use the sliding parallel motion; that is, they have substituted for the radius bars of the parallel motion of Mr Watt, a sliding bar or groove in which the top of the piston-rod is guided.

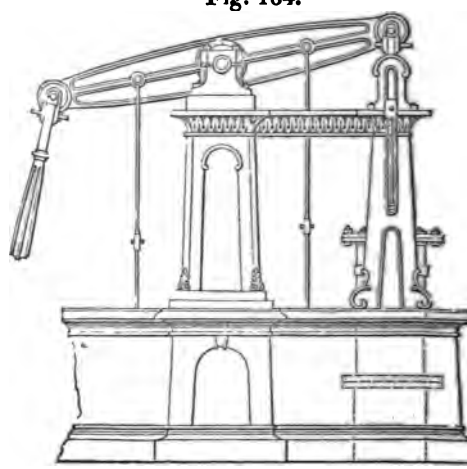
The head of the piston-rod *p*, figs. 163, 164, is enclosed between two flat surfaces, or between two parallel iron bars, which are kept in the vertical position by means of

Fig. 163.

stiff-framing: on these it slides, or to diminish the friction a wheel may be added; but there are reasons why this wheel does not in practice work very well, and the plain slide is therefore preferred. In fig. 163 we have represented this motion as applied to an engine of the simplest form, and in fig. 164 to a beam engine.

Another species of parallel motion was, we think, first adopted in America; but it has also been used in this country. It is the engine with vibrating pillar.

Fig. 164.



The pillar, which supports the beam or lever, instead of being fixed in an upright position, has a joint at the bottom, as will be seen in fig. 165, on which it and the

beam and the crank-rod perform a joggling motion backwards and forwards during each stroke. The motion is of the ollowing nature.—The point s, fig. 166, is fixed; so is s'; $s\,g$ and $s'\,g'$ are movable bars; $p\,g$ is $\frac{1}{2}$ of $p\,g'$. The point g describes a circle round s, and g' round s': hence p describes the curve $p\ s\ p'$, of the sixth order. The oscillation of the moving mass of the engine in alternate directions, with a sudden jolt at the end of the stroke, renders this a bad engine when made on a large scale; and it is obvious that the deviation of the piston-rod from the straight line is very great.

Fig. 165.

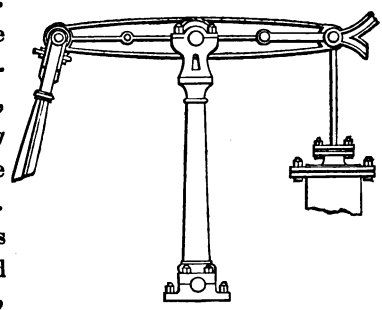
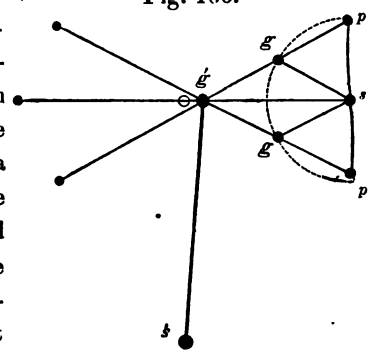
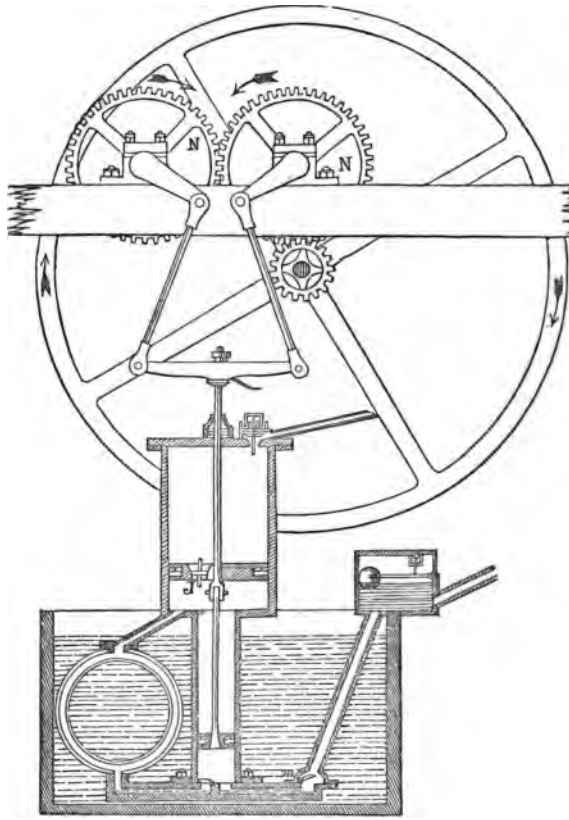


Fig. 166.



A very elegant parallel motion was invented by the Rev. Mr Cartwright, and applied by him to the steam-engine so early as 1797. Two equal toothed wheels N N, fig. 167, work into each other, and from corresponding points of their circumference two connecting links unite at the extremity of a cross bar, to the middle of which the piston-rod is joined. These wheels and connecting rods being

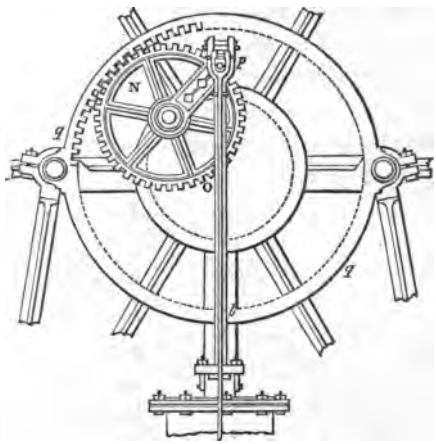
Fig. 167.



always in similar positions on opposite sides of the piston-rod, the obliquity of their actions balances each other, and the rod describes a straight line. But it is difficult to make and to maintain the wheels of this machine in the state of accuracy and perfection necessary to its working well.

The cycloidal parallel motion is one of high geometrical beauty. It was invented by Messrs Fenton, Murray, and Wood, and applied to the steam-engine in practice in 1802. It depends on this principle that an encycloidal curve, described by one circle rolling within another,

Fig. 168.



approaches a straight line as the inner circle becomes more nearly equal in diameter to the radius of the outer one. For the purpose of applying this principle, a large wheel *q q*, fig. 168, with teeth on its inner circumference, is fixed on a frame concentric with the axis and circle of the crank O O. N O is a wheel with external teeth, which is fixed freely on the crank-pin, and *p* is the point of attachment of the piston-rod *p l*. By this arrangement the small wheel N O is compelled, by the pressure of the piston-rod upwards, to roll round the great circle, ascending on the one side, and descending on the other, so that the distance of the end of the piston-rod from the

point of contact of the circles is always equal to the distance of the circle from the diameter; (or, $n \mp r.\sin.e = \pm \frac{1}{2} r. 2 \sin. e.$) and thus the straight line is always preserved. We have seen this motion working very well.

But the principle which furnishes the most perfect parallel motion, is one which, although it be well known, we have never seen applied to practice. It is well known that the locus of the extremity of a straight line, the middle of which moves in a circle, the other end being confined to one straight line, is also another straight line at right angles to the former. Let a straight bar $x\,y$, fig. 169, be placed with one end y confined in an horizontal groove $a\,s$, and let a pin in the middle g be allowed to slide in a circular groove $y\,g\,x$, then the end x will always describe a straight line $s\,x$ perpendicular to the first. Or it may be thus modified. If the arc of a semicircle have one of its extremities placed in a given straight line, while it moves along a given

Fig. 169.

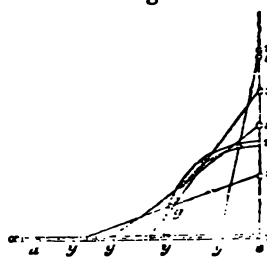
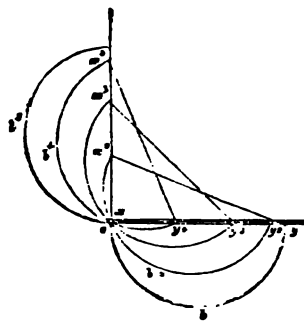


Fig. 170.



fixed point, the other extremity of the arc will describe another straight line at right angles to the former. Let a semicircular round bar y b x, fig. 170, be allowed to slide through a fixed centre at s, the one end y sliding in a groove, or along a bar $s\,y$, then the point x will describe the perpendicular $s\,x^4$, a perfect straight line.

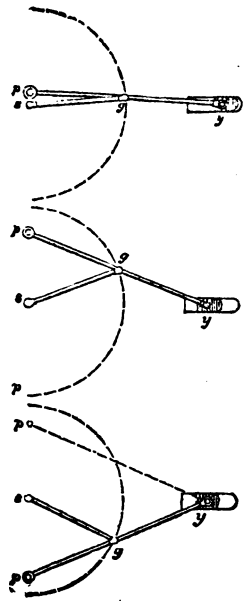
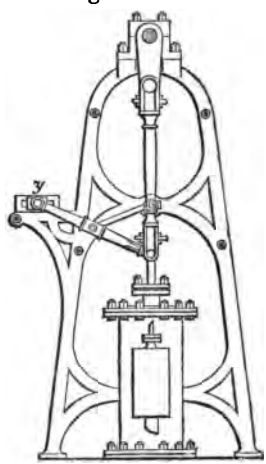


Fig. 171. Fig. 172. Fig. 173.

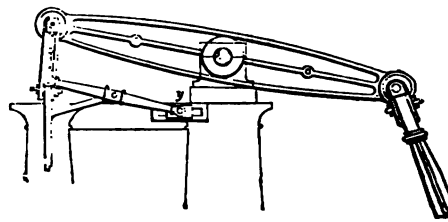
To put this in practice in a form which shall not deviate widely from received forms of construction, is not difficult. The semicircular groove, and the semicircular bar, are not good constructive expedients. But if we take a radius bar s g, figs. 171, 172, 173, fixed at a centre s, so that its end g describes a circle freely round it; and if we take a rigid bar $p\,y$, of double the length of $s\,g$, and united to it at g, then the middle of $p\,y$ being thus constrained to move in the circle round s, we have only to permit y to slide freely in an horizontal groove,

Fig. 174.



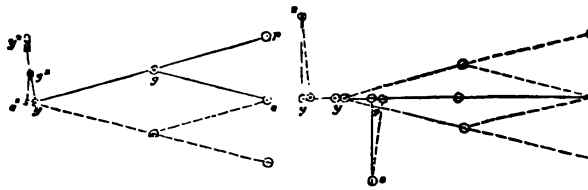
and the point *p* being carried up and down, will describe the straight line *p s p*. Fig. 174 shows the application of this motion to the simple engine, and fig. 175 to the beam engine.

Fig 175.



Mr Oldham of the Bank of England has shown us an application of this principle, of which he has made a model he adds a refinement which diminishes the friction at *y*, while it introduces an infinitesimal error of the second degree. To the end *y* he has attached Watt's parallel motion, as represented in fig. 177; *s g g s* being the radius bars, and *g y g* the connecting link on a small scale, the point *y* is by this parallel motion guided in the horizontal direction. Instead of this refinement, which only produces infinitesimal error, we propose, if it were re-

Fig. 176. Fig. 177.

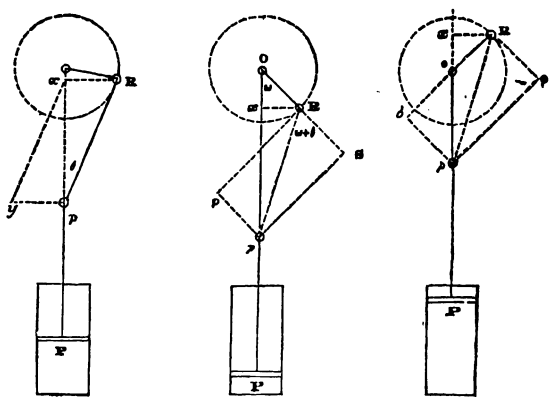


quired, to preserve the principle without error, and to introduce only infinitesimal friction. This we accomplish

by placing a secondary geometrical motion like the primary one upon the point y, fig. 176, so that its motion may take place in a perfectly straight line. The effect of the friction will thus become an infinitesimal of the third order. These last refinements are, however, of a higher order than the degree of practical precision in the steam engine usually requires.

Such is the mechanism which the obliquity of the direction between the connecting rod, or link, renders necessary to prevent any of the motion, propagated through them, from being expended in producing oblique transverse motion in the top of the piston-rod. Still, however, the motion of the piston-rod is modified by transference in an oblique direction, and we have now to consider the nature of that modification. Suppose the crank O R to be

Fig. 178. Fig. 179. Fig. 180.



in the position in the diagram fig. 178, where the connecting rod p R is at right angles to it; then the connecting rod p R makes with the piston-rod Pp an angle Op R or θ.

The force F therefore, acting along the piston-rod Pp, being represented by the length of $p\,x$, and $x\,y$ and $p\,y$ being drawn parallel to R and R $p\,x$, we see that the line $x\,y$ or p R $= \frac{F^1}{\cos.\theta}$ represents the force in the piston-rod along the crank-rod, tending to make it revolve, while $p\,y = R\,x = R\,p \sin.\theta = F.\frac{\sin.\theta}{\cos.\theta}$ represents the amount of pressure sustained by the parallel motion.

Thus we have a true representation of what takes place when the connecting rod, instead of being in a line with the piston, or parallel to it, is at right angles to the crank; and in this case the whole force communicated in this oblique position to the crank-rod, acts immediately and entirely in turning round the crank. But at other points, such as are given in the two succeeding figures, the motion is again modified by the obliquity of the direction of the connecting rod p R to the crank O R. If O R be prolonged to S, and from p a perpendicular dropped upon it, and the parallelogram R ρ p σ completed, we shall have the diagonal force p R resolved into R σ and R ρ; whereof R ρ alone tends to turn round the crank, R σ producing only pressure towards the centre. In this case the angle p R σ is equal to the two interior angles of the triangle p R O, that is to $\omega + \theta$, the sum of the angles of the connecting rod and crank with the line of the piston. Hence the whole force in the connecting rod becomes resolved into p R. cos. $(\omega + \theta)$ and the whole force of the steam on the piston-rod becomes on the extremity of the crank F. $\frac{\cos.(\omega + \theta)}{\sin.\theta}$

The Piston.—The next elementary part of the steam-

engine, upon which much of the efficiency of its operation depends, is the piston. Pistons were at first very rude implements for steam to work with. A large block of wood cut round to fit the inside of the cylinder, and driven very tight so as pretty nearly to fill up the cylinder, was considered a sufficient obstacle to resist the passage of the steam, until it had performed its duty, either of driving the piston from the bottom to the top, or from the top to the bottom of the cylinder. It next became usual to cover this piston with leather ; but the heat of the steam soon dried up the leather, and deprived it of the requisite pliability. The next step was to make the piston of metal, like the piston of Otto Guericke's atmospheric engine, and then to make a groove around this piston, which was filled with bands of plaited hemp, now technically called a gaskin, so put together as to be spongy and elastic, and to interpose this elastic substance between the piston and cylinder, so that the hemp, yielding to the inequalities of the cylinder, should fill them up without permitting the steam to escape. This has been successfully used for a long period, and, where the cylinder is in good condition, used with advantage : and it is still very extensively employed. Instead of using a solid piston with a groove for the hempen packing, it was found better in practice to contruct the piston as shown in fig. 181. The lower part of the piston is formed of a plate attached to the piston-rod; the under-edge of this plate is of a diameter a little less than that of the cylinder, and it gradually curves inwards, so as to form the lower portion of a groove for the packing. The upper part of the piston consists of a plate with a similarly curved rim, completing the groove. This

Fig. 181.

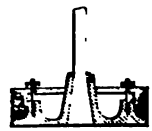


Fig. 183.

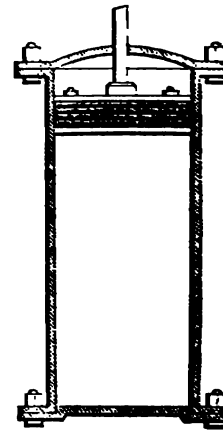
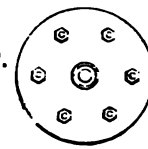


Fig. 182.



upper plate is called the piston-cover, and is attached to the lower plate or body of the piston by screws. In the groove are carried round bands of soft plaited hemp or gaskin, which fill up the cavity; and as the gaskin wears, the upper plate is screwed closer to the lower one, and forces the packing against the sides of the cylinder. The piston is represented *in situ* in figure 183.

The only fault of this hempen packing, is its liability to wear out, and become rigid and unelastic. A plan was next adopted of protecting this hemp, and still using its elasticity. Around the piston, in front of the packing and enveloping it, two brass hoops, fig. 185, with slits in them, were placed, to protect it from contact with the cylinder. These slits allowed the hoops to enlarge and contract their diameter, in correspondence with the inequalities of the cylinder; while by the elasticity of the hemp, they were kept continually pressed out in contact

with the surface. This simple metallic packing is represented as applied to the piston in figure 184.

Fig. 184.

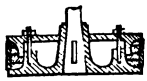


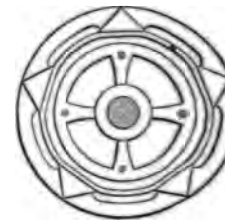
Fig. 185.

A still more independent metallic packing is produced in the following manner, so as to dispense altogether with the elastic action of the hemp. Large metallic belts of considerable thickness are cast, so as to form solid rings, about a hundredth part greater in diameter than the inside of the cylinder they are to fit, and turned on a lathe truly cylindrical to that diameter. A small portion is then cut out of the circumference of each ring, so as to make them open hoops like those represented in the last figure; and the two open ends are then forcibly brought together, until their diameter is just such as to admit them into the cylinder, their ends being now in contact so as to form complete rings, and they are again placed in the lathe and turned truly cylindrical. By this arrangement it is brought about, that the elasticity of the rings continually urges them outwards, towards their original diameter, and so dispensing with the elasticity of the hemp, forms a packing wholly metallic. This is employed on a large scale by some of the very best engineers in this country, and is greatly to be recommended for its simplicity. Of course the break in the ring would allow steam to pass; but this is avoided either by interposing a metallic tongue at the break, or by using a number of rings, so that the break in one of them may be opposite to the sound portion of the other.

Another form of piston may be called the wedge metallic piston. The rings are cut into a number of parts, and are pressed upon the cylinder by wedges, which again are kept in their places by springs; and so it is supposed that a more perfect adaptation is gained of the parts of the ring to the cylinder. This is certainly the case; but the ring is much more complex than in the other form:—

Fig. 186.

Fig. 187.



In fig. 186, wedges are shown to be inserted behind the rings, with springs behind them, forcing them outwards; and in the figure 187, a single elastic hoop is substituted for all those springs. Springs without wedges are also in very common use for metallic pistons with divided rings, double sets of rings being used, and the springs pressing directly on the segments of the metallic rings, as in figs. 188, 189.

Fig. 188.

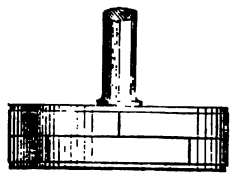
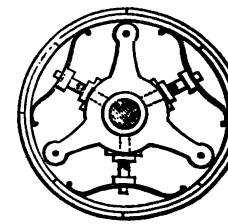


Fig. 189.



A stuffing-box is an apparatus used in immediate connexion with the piston. A simple aperture in the cylinder-cover to permit the passage of the piston-rod, as in fig. 190, could not be made steam-tight: so that to prevent the escape of steam, a stuffing-box has to be made use of. This consists of a box cast round the hole of the cylinder-cover, fig. 191, in which is laid, around the piston-rod and in contact with it, a large quantity of hempen packing. This packing is lubricated with oleaginous matter, and the ring, fig. 192, is then placed on the top of this mat-

Fig. 190.

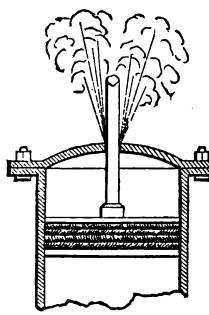


Fig. 191.

Fig. 192.

ter, and pressed hard down upon it by screws, so as to squeeze the stuffing into every crevice. Stuffing-boxes of this description are employed wherever it is necessary to pass a rod out of a vessel, or into it, without permitting the escape of the steam. Thus there is one at the entrance of each valve-rod into the steam-chest of the cylinder valves, and also, wherever a rod passes into the interior of a boiler.

The governor is an appendage to a steam-engine, of much value in all its applications to the production of uniform revolving motion. It is merely a modification

of an apparatus similar to the pendulum, and by which Huyghens once attempted to make a time-keeper instead of the common pendulum. If we suppose the axis A x, fig. 193, to revolve on its centre, and the ball B hung by a thread from x, two pieces of iron, x C and x C, being bent so as to form cheeks, of a form called the cycloidal curve; then when the string B x comes in contact with the cheeks, it will perform each semi-revolution in the same time in which it performs two oscillations as a common pendulum; that is, if it be 39.1 inches from the centre of B to x, the pendulum will revolve once in two seconds. If, however, the ball B be suspended from x by a straight bar, such as B x in the next figure, the line B x in deviating from A x will describe the circular arch A B, instead of a cycloid as formerly, and the time of oscillation will vary as the ball recedes from A, the revolutions being more rapid at b than at B. If in the position B, the line x C be 39.14 inches, then will the revolution be performed in two seconds, or at the rate of 30 revolutions per minute; while at b they will be performed in less time, and between B and A more slowly; and in general to find the height C x for any required number of revolutions, it is only necessary to find by the rules for calculating the rates of the pendulums of time-keepers, what length of pendulum will give double that number of beats per minute, and

Fig. 193.

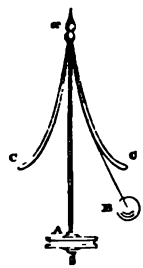
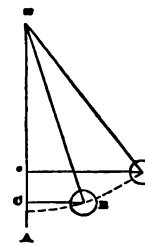


Fig. 194.



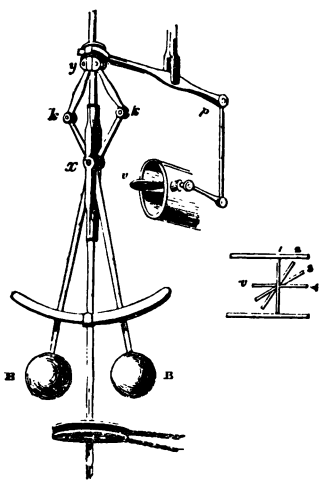
that is the desired height for C x. The rule for this purpose is easy. Divide the number 35226 by the square of the number of revolutious per minute, and the result is the height C x. Thus to find the length of A x for 30 revolutions per minute:—

30 squared = 30 × 30 = 900)35226(

required height = 39.14 inches.

The required regulation is effected in the following manner:—

Fig. 195.



The balls B B, fig. 195, are suspended by rigid bars from the centre x, and are prolonged to k k. These bars are joined by links, k y and k y, to a moveable socket y, which can slide up and down the axis. The straight lever y p is acted on at one end by y, and at the other it draws or pushes down or up the handle of a circular disc v, so as either to close it or open it to different degrees; this disc

is in the steam-engine placed in connexion with the steam-pipe that supplies the cylinder, so that if the engine should at any instant move round too slowly, from having too much work to do, the balls will collapse, raise up *y*, and open *v* to the fullest extent, as at 4, in the small sectional figure to the right; 3 being the mean position; while, on the other hand, should the engine, from its work being taken off, go round too quickly, the balls would fly off from the axis, bring down *y*, and close the valve to 2; or if it had happened, as by an accident, that the load was suddenly withdrawn, close the valve altogether, as at 1 in the side figure.

But the action of this governor is not always sufficiently delicate, its power of adjustment being somewhat slow. An improvement has been made upon it by Messrs Cheetham and Bailey, of Staley Bridge, in Lancashire, which renders its action much more rapid. On the centre of the throttle-valve, as the disc *v* in the steam-pipe is called, there is placed an iron tube, like a gun barrel, partially filled with mercury. When this tube is held perfectly horizontal, an equal quantity of mercury lies in both ends; but, on the contrary, when the slightest inclination is given to either end, the mercury instantly preponderates to that lower end, and suddenly changes its inclination in either direction. In practice we have seen this work well.

Of Condensing Apparatus.—The parts of the condensing steam-engine which we have hitherto examined, are in all respects identical with those of the high-pressure steam-engine. The characteristic difference consists in the manner in which the steam is disposed of after having produced its effect, and in the apparatus re-

quired for the purpose. In the high-pressure steam-engine, the steam is discharged from the cylinder simply by allowing the entering steam to press the piston upon the outgoing steam, and force it through the eduction-pipe into the open air. Now, it requires considerable force to effect this; we know that the atmosphere must be pushed away before the steam with a force equal at least to 15 lbs. on each square inch of the surface of the pipe; and therefore this amount of the force of the steam, which is a balance for the air, that is, an atmosphere of steam, is consumed or thrown away in this employment. In the condensing steam-engine this atmosphere is saved. The steam is annihilated almost instantaneously. A vacuum is formed on one side of the piston by this annihilation, and the steam is allowed to employ that part of its force, which formerly was spent in the useless labour of forcing the steam into the air, in forcing the piston through the performance of useful labour.

If, therefore, we take a high-pressure engine, such as we have already described, and if we desire to form it into a condensing steam-engine, we must add to it a large reservoir of cold water, named the cold well, such as is described in one of Watt's steam-engines, in the historical part of this treatise; and in this reservoir we must place a close vessel having an aperture or small pipe in it, from which a jet of water shall play and spread over the interior, so as to form a condenser, into which shall be conducted the eduction-pipe, by which the steam is led out of the cylinder. The quantity of cold water thrown into this vessel to cool it, will require to be six or eight times as much as is boiled off in the shape of steam. Attached to the condenser is a blow-through valve, opening outwardly

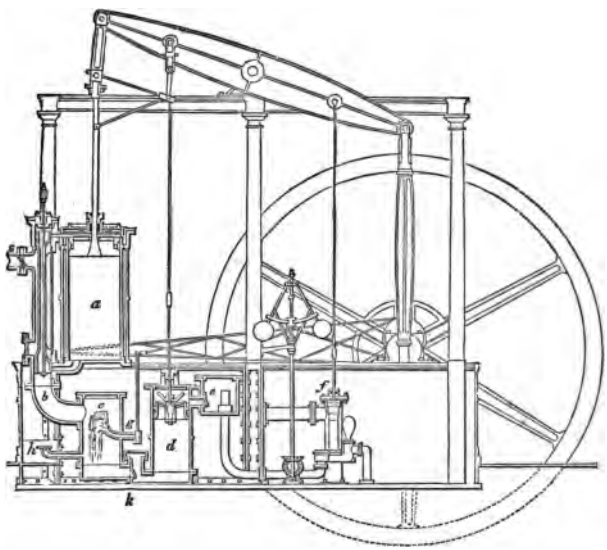
which allows the whole condenser, before starting the engine, to be filled with steam, so as to blow out at the valve all the air that may have previously got into it. The reader is referred to the historical part of this treatise for those parts in the description of Mr Watt's engine, and also to plates, and their descriptions of the parts of steam-engines at the end of the volume.

It must already have occurred to the attentive reader, that such a condenser as has now been described could not act efficiently for any considerable time. On the contrary it would rapidly become filled with water; for it is plain that the jet of water entering the condenser will fill it up at last with water; and even were this not the case, it is plain that the whole steam which passes through the engine being turned back into water in the condenser, this water would accumulate and fill the condenser. This water must therefore by some expedient be removed out of the condenser without admitting the air. And again, it is well known that all water contains a large quantity of air mingled with it, and permanently retained in its pores, but which escapes from it the moment it is placed in a vacuum. Now, this air would of itself accumulate rapidly to such an extent as to fill up the vacuum of the condenser, and render it inefficient. Air must therefore be removed out of the condenser, along with the accumulations of injection water, and the condensed water of the steam; and therefore an air-pump must be provided, capable of removing air and water from the condenser. This air-pump is placed beside the condenser in the cold well; communicating with it by a foot-valve, which permits the air and water to go out and prevents their return; and

delivering that air and water which it removes into another smaller reservoir, named the hot well, from the circumstance that the water withdrawn from the engine has been made warm by contact with the hot steam which it has condensed, and which it does not generally cool to a lower temperature than 80° or 90°.

These appendages of the condenser, the cold well, the injection-pipe, the air-pump, the hot well, the blow-through valve, the foot-valve, the delivering valve, &c., are represented in the following diagram, in a usual arrangement.

Fig. 196.



a is the cylinder, *b* the eduction-pipe, *c* the condenser, *h* the blow-through valve, *g* the injection cock and pipe,

c the foot-valve, *d* the air-pump, *e* the hot well, *f* the cold-water pump.

The reader will find other arrangements of these parts in the plates and their descriptions. The air-pump is generally worked by the great beam of the steam-engine, as in the figure, and is about half the area and half the stroke of the cylinder of the engine.

The cold well requires a continual supply of water, either from a running stream, or to be forced up by a pump like that marked cold-water pump in the figure.

Dry condensation is a subject which has attracted much attention from machinists; that is to say, it has been considered very desirable to condense the steam without injecting water amongst it. Mr Watt originally condensed in this manner. He merely placed upright pipes among cold water, and letting the steam into them, allowed it to be condensed by simply coming in contact with the inside of these tubes, which thus formed a condenser. The introduction of a jet of cold water was thus avoided, the introduction of air along with the water was also avoided, and thus the air-pump had its duties much diminished. But the efficiency of the engine was found to be very materially impaired; for the instantaneous annihilation of the steam was not effected, in this process of mere surface condensation, in the efficient way in which it had been by the old system of injection by a *jet d'eau*.

On the Rotatory Steam-Engine.

The steam-engine being now most generally used in our workshops, our manufactories, our steam-ships, and our locomotive engines, for the purpose of *turning round* certain axles or wheels with a continuous whirling or re-

volving motion, it has appeared to many the simplest, the most elementary, and the most appropriate manner of applying the moving power, that the steam should itself follow the wheel which it turns, round the circumference of its circle of gyration, and so it is supposed, by acting immediately and directly on the wheel to be turned round, produce the most powerful effect. In this way the action of the steam would be made to resemble the turning of a mill-wheel by the action of the water on the buckets of its rim; and the arrangements by which such an elementary mode of action might be brought about, form what is called a ROTATORY STEAM-ENGINE.

That simplicity of form and of outline are essential to simplicity of action, and excellence of mechanical action, is a fallacy; that simplicity of figure and fewness of parts are objects of higher importance in machinery than durability, precision, and economy of operation, is a fallacy; that such an elementary machine, if constructed, could give forth any more of that power than is now rendered effective by the common steam-engine in every-day use, is a fallacy, arising in ignorance, ending in disappointment.

We have to state with regret, that very injurious consequences have arisen from this popular error. Many men of high talent and inventive genius have sacrificed their talents, their industry, their lives, to this delusion. The patent-offices of England, Scotland, Ireland, and France and America, the mechanical periodicals of them all, the transactions of societies for promoting the arts, the "machines approuvées par l'Académie," the journal of the Franklin Institution, all teem with inventions of rotatory engines, and substitutes for the crank of the common steam-engine, by which power and sim-

plicity are to be united in the highest degree. And yet, when we look around us, we nowhere find that a phalanx of talent thus concentrated with a singleness of purpose, and an indomitable perseverance worthy a more hopeful object, has ever been successful in producing one form of mechanism to stand in competition with the common every-day reciprocating engine, with its crank and its fly-wheel and all its much condemned appendages. In this country alone a crowd of inventors have not only proceeded so far as to expend their ingenuity, labour, and money, in inventing and constructing machines of this class, and making them the subject of experiment, but more than a hundred of them have actually laid out in succession four or five hundred pounds a-piece in procuring the royal grant of monopoly for their valuable contrivances. We feel it, therefore, to be our duty to give a full and uncompromising exposure of the fallacies of the rotatory engine. We regard such a fallacy as a grievous obstruction to the advancement of the arts and the industry of Great Britain. It is to the prevalence of ignorance on this subject, that much of the misdirection of mechanical talent, in so far as it has been applied to the improvement of our prime movers, is to be attributed. Again and again, year after year, do we find the same machine invented and re-invented, and the same experiments repeated and the identical failures encountered. Of these failures, however, there is only a small number comparatively which comes before the public. Those alone which obtain patents are dragged into light; and of these we are only left to infer the subsequent failure, from the circumstance of discovering that their existence is recognised nowhere except in the parch-

ments of the Patent-Office. It is indeed a matter of general regret, not limited to the subject of rotatory engines, that false pride should prevent men from publishing the results of such experiments as may not be perfectly successful in accomplishing the objects originally intended. It should be recollected, that, as evidence of the truth or falsehood of some great principle, no experiment is valueless, if simply and faithfully described; and that, if it do not serve as a signal-post to point the way to truth, it may at least prove useful as a beacon to warn from the path of error. It is to unsuccessful experiments that we owe many of our most valuable scientific discoveries. The failure of an attempt to make a sucking pump more than 33 feet long, led to an acquaintance with the doctrine of atmospheric pressure, and opened a new field of research to the genius of Galileo, Torricelli, and Boyle; and Sir Humphrey Davy is reported, on an occasion where he was shown a dexterously manipulated experiment, to have exclaimed, "I thank God I was not made a dexterous manipulator, for the most important of my discoveries have been suggested to me by failures." Thus we find that the record of error may often prove a contribution to truth; and the man who is sufficiently unselfish to impart to others the benefit of such experience, is the disinterested friend of science. Had all the failures of the rotatory engine been publicly recorded, that avenue of misdirected effort would long ago have been closed.

Our present object is to bring together and place under the eye of the reader, all that has been done upon this subject; the attempts that have been made, and the failures of those attempts. We shall thus show that the

attempts at a successful rotatory steam-engine which are every day produced, are mere repetitions of experiments which have long ago been tried in circumstances precisely the same, and have long ago hopelessly failed and been abandoned: that these attempts were made in circumstances that were well suited to ensure their success, had success been possible. Let it be recollected that the only office performed by machinery, is the transmission of power from an animal or element, and never the creation of power. It can modify motion in direction, velocity, and force, so as to expend itself in one manner rather than another, but it can never create motion or generate power. This is true, or all the experience of the laws of matter which has been obtained since the use of inductive philosophy is false. Solid matter may obey force and modify it, but can never create power. The only enquiry to be made, therefore, in regard to any engine is this: when force is applied to the machine, whether the force of steam or any other, does it turn all the force of the agent to a useful purpose, without further diminution than is occasioned by necessary friction and resistance of the air, and the least possible loss of power by transmission? When steam bursts a boiler, or water overturns the embankment of a reservoir, the power of heat and of gravity produces its full effect; but it is not a useful effect. The object of a machine is to expend it parsimoniously in rendering the greatest portion of its effect useful. The only question entertained is, which form of engine is best calculated for converting the power of steam to a useful purpose, so as to do so with the smallest diminution in its quantity?

The common, or reciprocating steam-engine, is dis-

tinguished from the rotatory steam-engine by the nature of certain parts of its mechanism, which convey the motion of the steam to the machinery which is to be moved: these are a piston-rod and crank. Now, it is owing to a radical misconception of the nature of this elementary machine, the crank, that innumerable schemes have been devised for the production of circular motion, without the intervention of the crank, either by giving to the steam itself an immediate circular action, or by the substitution of some other less elementary mechanism between the reciprocating piston and the revolving axis, as the means of producing its rotation. In the most common form of the rotatory engine, the cylinder, piston-rod, and cranked axle are superseded by a cylinder, valve, stop, and axis. In the same way as a mill-wheel is compelled to move in a circle, either by the direct action of water or wind upon it, so is the drum, or wheel, with valves, fans, or other projections on its circumference, urged round by the force of the steam, and, enclosed in an outer cylinder, or case, gives revolution to an axis to which it is attached. This direct rotatory action of the steam will, it is imagined, give out the effect of the steam more powerfully, uniformly, and economically, than the common mode of reciprocating action when converted by the crank into revolution.

Rotatory engines may be arranged, according to their manner of action, into four classes:—

1st Class—Rotatory engines of simple emission.

2d Class—Rotatory engines of medial effect.

3d Class—Rotatory engines of hydrostatical reaction.

4th Class—Rotatory engines of the revolving piston.

As closely connected with the rotatory engines, in the fallacy which has given rise to most of them, we may add a series of inventions, forming a—

5th CLASS—Revolving mechanism substituted for the crank.

CLASS I.—The rotatory engine of simple emission forms the earliest, as well as the most rude and elementary, method of giving motion to mechanism by the escape of vapour or steam. It is described by Hero of Alexandria, in his *Pneumatica*, upwards of 120 years before the Christian era, and depends for its effect upon the same principle which gives to a rocket its career, and makes a fire-wheel revolve in displaying its beautiful lights. In these, as in all instances where fire or steam, or any fluid or gas is generated in a chamber, from which it is permitted to issue with violence, it will, in its exit, drive the vessel from which it issues away from it in the opposite direction: and it is, in fact, merely an application of the principle of recoil, where the gas generated by the explosion of the powder urges the ball outwards in one direction, and forces the breech of the gun backwards in the opposite one. The same recoil is felt in all cases of simple emission of a fluid from a reservoir; and if it be so arranged that water, steam, air, or the gaseous product of gunpowder, rushes out of a chamber through the arms of a revolving wheel, the openings of escape being properly directed, the recoil will urge round the wheel, and we shall have a revolving engine of simple emission. By availing himself of this principle, the machinist of Alexandria produced a working engine, merely by heating a vessel containing water and air, and allowing the

vapour to rush from two opposite orifices, at the end of two arms proceeding from a sphere, which the emission was employed to move.

Instead of using the principle of recoil, the force of steam, issuing with violence as we see it from the mouth of a kettle or boiler, may be directed upon the naves of a wheel so as to blow them round; and thus we have a second variety in the manner of converting the simple issue of steam into a moving power. This second species of the rotatory steam-engine of simple emission was invented by Branca, 1629. Since that time the engines of this class have been frequently re-invented and slightly modified.

The theory of machines of simple emission has been frequently and fully investigated; and the result is, that there is no possibility of obtaining by simple emission, in the most favourable circumstances imaginable, more than one-half of the whole power of the steam, so as to make it available to useful mechanical effect. The other half is wasted in giving off its impulsion to the air, or is expended in a current equally unavailing. Practical experience corroborates the predictions of theory. Smeaton and Pelectan have made the machine of simple issue the subject of careful experiment:—3 parts out of 11, 8 parts out of 27, and 2 parts out of 5, are the highest measures of the useful effect that it has been found practicable to attain; and by no possible improvement can more than one-half of the whole power be turned to a useful effect.

Class II.—Rotatory engines of medial effect are those which do not immediately give revolution to an axis, by the action of steam upon the wheel, but have a medium of communication between the power and the effect, which

medium is the direct agent in circular motion. This class of engines will be well understood by taking as its type any simple steam-machine, such as Savary's or Newcomen's, used for raising water; which water, by falling on the floats of a common mill-wheel, will then give rotatory motion to it. The engine of Savary raises water by pressing directly on its surface: and it is only necessary to allow this water to fall on a wheel, and it will be made to revolve, and form an engine of the second class.

A variety of this class has been invented, of which the Fire-wheel of Amontons is a type. The steam pushes water through certain channels that form the arms of the wheel, from a set of chambers on one side of the wheel, to a corresponding set of chambers on the opposite, and thus the side filled with water preponderates over the other, and the wheel revolves. The water being constantly driven off by the steam from a given side of the wheel to that opposite, uniform revolution is the result of the weight of the water. In this case, although steam is the agent, water is the means of communicating the rotatory motion.

Solids have also been made the medium of effecting rotation in this manner. Weights of solid matter, in the form of pistons, have been transferred by the force of steam to a considerable distance from the centre on one side of a wheel, and drawn nearer to it on the other side, so as, by bringing about a continual preponderance of one side, to effect a revolution. Watt and De Witty have designed arrangements of mechanism of this nature.

In this class of engines the loss of effect is manifest; for it is necessary that the steam, in order to produce the circular motion, shall give out its force in setting the ma-

dium in motion, and in overcoming the very great resistance of the liquid in all the pipes and passages and valves, through which it is transmitted to alternate sides of the wheel in every revolution. The force thus subtracted from useful effect, is power lost.

In those which move weights from and towards the circumference, there are mere groups of reciprocating pistons, without cranks, and partaking of the defects to be explained in Class V. In fact, in the engines of Watt and De Witty of this class, we have a number of reciprocating engines ranged round a wheel to do the work of one.

In the case of the fluid medium we have not only a loss of all the power expended in moving the medium itself, but also the additional loss of effect encountered in all modes hitherto adopted for applying a fluid to the rotation of a wheel; a loss, in the best examples ever presented in practice, amounting of itself to more than $\frac{1}{6}$th part of the power.

Class III.—Engines of hydrostatical reaction are more effective than either of the former classes. As invented by Watt, in 1796, this species of engine consisted of steam-vessels, in the form of hollow rings or circular channels, with proper inlets and outlets for the steam, mounted on horizontal axles, like the wheels and buckets of a water-mill, and wholly immersed in some fluid. These tubular wheels were made of iron, six feet in diameter, and the reaction of mercury was employed to give revolution to them. The engine moved, but was found to be inefficient, and was abandoned, although it had been tried in very favourable circumstances. The principle of action is this. Steam is admitted into a circular channel, or chamber, on the circumference of a wheel. This

chamber is partially filled with some liquid: the pressure of the steam is expended in pushing the mercury in one direction, and the end of the chamber in the opposite way: so that, while the liquid is thus forced out of the chamber, the chamber is by an equal force pushed away from the liquid. The wheel is thus moved round. It is apparent that a part of the force is employed in propelling the wheel, and the remainder is expended in overcoming the resistance of the liquid of reaction, and expelling it from the chambers, which remainder is a large portion of the power withdrawn from useful effect.

Class IV.—Rotatory engines of the revolving piston are constructed on a much better principle, and hold out much fairer prospects of successful competition with those of the reciprocating piston, than any of the species of the first three classes that have been already considered. In these classes the steam is not confined in rigid vessels, but its action is expended in producing currents in fluids, and expending motion in medial effects, which are useless. This is not the case in the steam-engine of the revolving piston. The steam is confined in a close and rigid chamber, and acts only on solid inflexible surfaces, and escapes along confined passages, so that its full effect may be obtained in useful work. Abstractly considered, it is an engine capable of giving out the full power of the steam, and, therefore, may fairly be imagined to come into competition with the ordinary reciprocating crank engine. The objections to it are entirely of a practical nature, and regard the engine, not in its abstract mathematical form, but as a machine made of destructible matter—of matter imperfectly elastic—of surfaces offering resistance to motion—of matter obeying

the known laws of motion and rest. These objections are not the less valid that they are of a sensible and tangible, rather than a speculative description. But, as a natural consequence of the more plausible deceptions held out by this species than by any of the three preceding ones, it has followed that the fallacies of this class have been more widely seductive than the others; and many eminent mechanicians have been led astray by them. The fallacy of this class of engines we shall expose in conjunction with the next class, as the same misconceptions lie, to a considerable extent, at the root of both.

CLASS V.—Revolving mechanism substituted for the crank of the common steam-engine, for the purpose of obtaining from the reciprocating piston a rotatory effect otherwise than by the crank, and in a better manner than by the crank, forms a class of inventions involving fallacies similar to those in which the revolving piston has originated. These two may therefore be considered together.

Although the name of Watt has been included in the list of inventors of substitutes for the crank, it should be observed, that he was only driven to the invention of a substitute by the circumstance of a patent having been previously obtained for the crank in its simple form; and that he abandoned his beautiful but more complex mechanism on the instant that the elementary crank was released from the fetters of monopoly. It is due also to his memory to say, that the sun and planet wheel, which he substituted for the crank, is a disguised crank, possessing all the valuable properties, excepting simplicity and smallness of friction, which give to the crank its present eminence as a mean of obtaining rotatory effect. It is remarkable that the fallacies regarding the now

universally employed crank were coëval with its first suggestion as the vehicle of rotative steam power. John Stewart, in describing his mechanism for this purpose, in the Philosophical Transactions, 1777, observes that "the crank or winch is a mode of obtaining the circular motion which naturally occurs in theory, but in practice it would be impossible, from the nature of the motion of the engine, which depends on the force of the steam, and cannot be ascertained in its length: and, therefore, on the first variation, the machine would either be broke to pieces or turned back." Mr Smeaton agrees with Mr Stewart on the inapplicability of the crank; but adduces another objection. "That great loss would be incurred by the absolute stop of the whole mass of moving parts as often as the direction of the motion is changed, and that although a heavy fly-wheel might be applied to regulate the motion, it would be a great encumbrance to the mill." In such phrase of evil omen was it thus confidently predicted, that the simple means now in every-day use for the communication of steam power to revolving machinery, would either be attended with great loss, be very dangerous in its action, or altogether break the machine to pieces. At that time, however, the crank was not in use; but the very same objections are still urged by those who have, every day, before them the practical confutation of their assertions.

I. In the abstract and purely theoretical view of the subject, it can be shown that the present mode of applying the steam possesses none of the disadvantages, and that the rotatory mode possesses none of the superiority attributed to it.

In making the comparison between the rotating and

reciprocating piston, let it be supposed that the vessels containing the steam are equally rigid, equally perfect in their form, and are equally divested of friction, and that there shall have been obtained for the steam a *point d'appui* as satisfactory in the case of the rotatory, as that which the reciprocating engine possesses in the ends of the cylinder; then, upon this hypothetical condition, neither engine will excel the other, each will move over a space with a power and velocity proportioned to the steam which it makes use of, and that engine will do most work which uses the greatest quantity of steam.

The great fundamental principle in the construction of machinery is, that the work done depends in quantity only upon the quantity and velocity of the power applied, and not at all upon the form of the machine; in other words, that a machine has no power, either of consuming or creating motive power; that it can only transmit it; that it can only modify it to suit particular purposes; and that what it loses in pressure it will gain in velocity; this is on the supposition, of course, that the machine is perfectly well made, without friction, and without permitting the escape and waste of power in some effect not conducive to the end in view. Setting out, then, from this great fundamental principle of virtual velocities, we might satisfy ourselves with asserting the truth we now wish to establish as a simple self-evident deduction from it, and conclude that from this great principle of virtual velocities there could not possibly be loss of power by the crank steam-engine.

This summary process would not, however, satisfy the enquirer or inventor who has taken the erroneous view of the subject, unless he were given to understand how

this great doctrine may be made to bear on the peculiar difficulties of the case. He will return upon us with the question—"How is it that, in the common crank, we are able to show that, at two given points in its revolution, the position is such that an infinite power would produce no effect at all: that there are only two instants of time in which the force and its effect are equal: and that, at every other point, the pressure given out by the steam to the crank is less than the original pressure of the steam on the piston? How is this inconsistency to be reconciled?" We think it right to give a direct answer to this question, because a considerable authority, Mr Tredgold, has committed a grievous error in reporting, and apparently demonstrating, that the rotatory and crank engines actually differ in theory in the proportion of 3 to 2—the proportion being against the rotatory engine: whereas, if they be not equal, our whole system of mechanics since the time of Galileo has been resting on a fallacy.

Let it be recollected, then, that at the two extremes of the line of centres the greatest loss is said to take place. Now, here the fact is, that it is impossible there can be loss of power, for there is no power at all exerted: there is no steam in action: it is forgotten that, at this point, the communication which supplies the steam from the boiler has been cut off. The steam on one side of the piston having done its work, only waits to be released from the chamber, and escapes on the instant of the opening of the eduction-valve, and at the same instant is in the act of being permitted to enter on the opposite side, for reversing the motion. At these points, therefore, all application of force has ceased, and arrangements are

making for reversing the motion; and, as no power is applied, none can be lost.

In regard to the remaining points of the circle, at which it is said that power is lost, it is easy to show that the velocity imparted to the crank is such as to be an exact equivalent to the force which is apparently lost. The following table presents the results of very accurate calculations of power and velocity, showing that the velocity at a given point in the circle is increased exactly in the same ratio as the force or pressure is diminished, so as at all times to present the same dynamical equivalent. The table extends from one neutral point to the other neutral point of the orbit of the crank, comprehending a semicircle divided into ten equal parts. The first column indicates the point in the semicircle at which the force and velocity are estimated; the next column shows the percentage of the direct force of the steam on the piston, which is given out in pressure upon the crank of the engine; and the last column, the velocity given out at each point.

Place of the crank.	Per centage of power given out in pressure.	Relative velocity.
0°	0.00	Infinite.
18°	30.90	3.236
36°	58.78	1.701
54°	80.90	1.236
72°	95.11	1.051
90°	100.00	1.000
108°	95.11	1.051
126°	80.90	1.236
144°	58.78	1.701
162°	30.90	3.236
180°	0.00	Infinite.

From this table it is evident that when we take note, as we must do in every correct estimate of power, both of force and velocity, the crank has at each point the equivalent in greater velocity for less force.

The numbers in the second column also represent the velocity of the piston in relation to the crank; so that, when the velocity of the crank is uniform, the velocity of the piston, or the steam consumed, which is proportional to its velocity, is in the exact ratio of the pressure on the crank.

The last consideration which we shall submit upon this part of the subject is, that if the average of the pressures on the crank be taken for every point of its orbit, it will amount to about 63.3 per cent for the whole circumference of the circle. Now, as the same circumference of the orbit of the crank is greater than the stroke of the piston in the cylinder, the whole space described in a given time by the crank is greater than the whole space described by the piston, also in proportion of 3.1416 to 2; so that, if we combine the greater length of the whole orbit with the force on it, we shall have an exact equivalent to the greater force on the piston moved through a smaller space.

The error of Mr Tredgold lies, not in his estimate of the effect of the crank, but in his estimate of the effect of the steam in the rotatory engine. By a strange oversight, he gives a statement of its power as much over the truth as that of the crank is generally stated under the truth. We admit that, in the first abstract view of the subject, the rotatory is theoretically a perfectly efficient propagator of power, and we have merely designed to show that in theory the crank has not the faults usually attri-

buted to it, and is also a perfect machine. We shall by and by show what the considerations are by which the impracticability of the rotatory scheme is exposed.

It appears, therefore, that the power of steam is by no means disadvantageously applied through the medium of the crank in the ordinary way; because, 1. the velocity of the crank is in the inverse ratio of the pressure upon it; 2. because the mean pressure on the crank during the whole revolution is less than the pressure on the piston, only in the proportion in which the whole space moved over by the latter is less than the space described by the former, so that the whole effect is equal to the whole power; 3. because the steam is not at all expended at the neutral points, and because its expenditure is at every point exactly proportioned to the pressure which it gives out, the velocity of the piston being in that ratio. In theory, therefore, the ordinary crank possesses no inferiority to the rotatory machine, as an engine for applying the power of steam to revolving machinery.

II. In a practical point of view, it may be shown, that the rotatory steam-engine is greatly inferior to the common reciprocating crank-engine in simplicity of parts, easy construction, cheapness, amount of friction, compactness, precision and uniformity of work, and durability and economy in use; and that it does not possess any of the peculiar applicability that has been attributed to it, to the great purposes of inland navigation and railway transport.

1. Simplicity.—A little unfairness is sometimes inadvertently used by inventors of rotatory engines, in making comparisons with their machines and the com-

mon crank-engine; they select the large beam-engine with all its conveniences and appendages, and compare it with the simplest form of the rotatory engine; but in justice we may be allowed to take the simplest form of both. Now, there is a simple form of engine used both in America and in this country, of the oscillating species as it is called, and this species of reciprocating engine consists only of the following parts:—cylinder, piston, and cranked axle; there are no valves or further mechanism of any kind, so that where simplicity is the first great requisite, this kind may be used with advantage. The rotatory engine of the most simple species must have its drum, diaphragm, piston, and axle.

If we take those forms of the rotatory engine which require valve-gear, air-pump, condenser, force-pumps, &c., such appendages will have no advantage of any kind, in either form; but in working the pumps which are themselves reciprocating, the reciprocating engine will have the advantage of more direct, immediate, and simple action; for in the rotatory engine additional mechanism is necessary to convert the revolving motion into one calculated for reciprocating pumps.

2. In ease of construction the simple form of reciprocating engines incomparably excels the rotatory. To possess equal powers, the rotatory drum would require to be of much larger diameter than the reciprocating cylinder; and the difficulty of construction increases in a high ratio with the diameter. The diaphragm is also a sliding or revolving piece of mechanism, whose rubbing surfaces require the greatest precision of workmanship. The revolving piston is also a practical problem of the greatest difficulty, and one which has never

been satisfactorily solved; for if it be rectangular with plane surfaces, it is scarcely possible to make its surfaces steam tight; and if it be a circular and revolving piston, its surface and that of the drum become surfaces of double curvature, and the difficulty is then prodigiously increased. The metallic piston of the common steam-engine is the most perfect and most simple piece of mechanism, which can be made by a very ordinary workman, and which, if imperfectly fitted, will, in the progress of doing its work, become of itself every day more and more perfect. An editor of a well-known practical journal, although a believer in the rotatory engine, speaking of one of its simplest forms, is compelled to admit, "that there being no mode described of making the parts of the engine steam-tight by packing, they must be all made so by accurate workmanship and grinding, the expense of which, in the outset and in repairs, would certainly be too considerable to allow it to come into competition with other steam-engines of a more common and practicable construction." His admission is equally applicable and fatal to all the forms of the engine.

3. The cheapness and first cost of the engine, will result from the two former points of inferiority, and will be further shown, from those which follow, to be greatly and necessarily in favour of the common engine. Not only are the parts, from their nature, more easy of construction, but the extent of polished surface will be shown to be much greater in the rotatory, than in the reciprocating engine.

4. The quantity of surface exposed to friction is greater in the rotatory engine. Let it be recollected that, in the rotatory engine, the piston describes the semi-

circumference of the circle, while the piston of the reciprocating engine is describing the diameter of it. Let it also be recollected, that the reciprocating piston passes back through the returning stroke, over the very same surface through which it formerly descended, while the rotatory piston necessarily revolves over a new surface, forming the other semi-circumference of its orbit. Let it also be recollected, that the form of the reciprocating cylinder may be so proportioned, that it may have a minimum of surface, while the length of the circuit of the rotatory piston prevents the possibility of giving it a proportion to the radius of the piston by which this object would be attained; for it would be equivalent to making a circle whose diameter should be equal to its circumference, which is impossible. It is impossible, therefore, that the friction can ever be as small in the rotatory as in the reciprocating engine.

5. Compactness.—It follows in like manner, that the bulk and space occupied by the rotatory engine must be greater than in the reciprocating engine; for in the one case the piston must describe the circumference of a circle, whose diameter is greater than twice the radius of the piston, and in the other case it is only necessary that the piston pass through the diameter of it.

6. In precision and uniformity of working, its inferiority will be rendered manifest under head III., when the peculiarities of the crank are explained.

7. In durability and economy in the wear and tear of ordinary working, the rotatory must, from certain elements in its constitution, be necessarily far inferior to the common engine. It contains in the very nature of its action, elements of speedy destruction and expensive and

frequent repairs, so that it can never become an economical engine. Before proceeding, however, to demonstrate the cause of this inferiority, the fact of this inferiority, as existing in all previous engines, we shall adduce from the unwilling evidence of a friend to rotatory engines. Speaking of Mr Halliday's engine, he says that, "the extreme accuracy and nice fitting of parts necessary for it, will make it very difficult to execute and very easily deranged. Rotatory steam-engines possess considerable advantages both as to speed and economy of power, and would therefore be preferable if they could be made to work as well for a continuance, and be as easily kept in good order as common alternating steam-engines; but from their being so very seldom used, we apprehend that this is very far from being the case with any of them at present, and that the production of a rotatory steam-engine possessed of these necessary qualities, is still an object of research." So far the Editor of the Repertory of Arts, in testimony that the rotatory steam-engine *never has* been made to work durably and economically; we now go on to show that it *never can.*

It is essential to the durability of a machine that its parts should wear uniformly, and that, if possible, the mere process of wearing should make them fit each other more closely. This is pre-eminently true of the piston and cylinder of a common reciprocating steam-engine. Its piston, cylinder, and valves fit more closely as they wear, and are worn with perfect uniformity, so as not to require repair, until, by long working, the whole thickness of matter in action shall at length have been consumed. This is the perfection of mechanism, and is admirably exemplified in the metallic piston of a steam-

engine, which, working night and day, will require no repair of any kind, until, after a long period of years, the whole strength of the metallic rings shall have been consumed.

In the very nature of the rotatory piston, this uniformity of friction, this increasing adaptation of surfaces, this permanence of the best working condition, is impossible. A common reciprocating steam-engine attains its best working condition after it has wrought for some years; but a rotatory steam-engine, if it have been brought by care and precision in workmanship to a state of high finish and perfect accuracy, so as to work well for a day, commences from that moment a rapid course of deterioration, every succeeding degree of which accelerates the progress of decay; a decay which can only be retarded by continual, laborious, and expensive repairs. The following considerations may render obvious the nature of the elements of self-deterioration in the constitution of a rotatory steam-engine.

Suppose two perfectly flat plates of polished metal perfectly round to be laid one upon the other, so as exactly to coincide at every point; let the undermost rest upon a table, and let the uppermost be so made as to turn round on an axis while in contact with the other, and let a rapid motion be communicated to the uppermost; let us consider what the result of the attrition of one of these upon the other will be: will they wear equally, so as to remain in a state of mutual adaptation, or will they not? Experience furnishes us with a reply that exactly quadrates with a reasonable expectation: they will not wear equally, they will not retain their form, they will not remain flat: they will wear

away most rapidly at the circumference, and wear open there while they are quite close at the centre. Let it be considered that the outer edge performs a larger circuit than a part nearer to the centre; that, therefore, since all the parts revolve in the same time, those nearer to the circumference move with greater velocity than those towards the centre; that the attrition is consequently most rapid at the circumference, and diminishes uniformly towards the centre of the plates; and it necessarily follows, that towards the edges the plates must commence an immediate and rapid waste, while the centre remains uninjured. This result is established as matter of experience. It is a circumstance that has caused the failure of many beautiful inventions. It is the reason why conical bearings have been universally abandoned for cylindrical ones; and it is the reason why a most beautiful class of inventions has been totally useless to the improvement of the common steam-engine; we refer to the revolving valves invented by Oliver Evans and by Murray, but now universally abandoned, in spite of their simplicity and original cheapness, on account of this inequality in the attrition of flat surfaces revolving round a centre.

The application of the result of this illustrative experiment to the subject in question, is abundantly obvious. The rotatory piston is necessarily and inevitably of this nature. Performing a circuit round a centre, different portions of the bearing surfaces subjected to pressure, and necessarily in contact, and requiring to be steam-tight, revolve at unequal distances from the centre, and therefore with unequal velocities; hence the circumferential surfaces, under this excessive attrition, wear more

rapidly, and become unfit for use long before the central parts have suffered any sensible effect. It is to this difference of velocity and of attrition, arising from the necessary circumstance of motion round a centre, which renders it impossible to keep the rotatory engine in a working condition with advantage, and from which it follows that each day's work renders the engine less fit for the duty of the succeeding day.

8. The peculiar applicability of the rotatory form of steam-engine to the purposes of steam navigation and land locomotion, has been much insisted on by projectors of rotatory engines. To both these purposes it is, from its form, supposing it to possess no other disadvantage, most inapplicable. In a steam-vessel, it is first of all desirable to have the axis of the paddles as high as possible, and the weight of the engine as low as possible. Now if the engine be placed on an axis, which is the case in this application of the rotatory engine, one of two evils is incurred: either the axis of the wheels must be brought low, which impairs the action of the paddles, or the weight of the engines must be exalted so as to render the vessel top-heavy, unsteady, or, as it is technically called, "crank," and liable to be upset. By the ordinary engine, the axis is elevated to or above the deck, while the weight of the engine remains on the floor, at the bottom of the vessel. Again, to the application of the rotatory steam-engine to the purpose of terrestrial locomotion in propelling carriages on railways or other roads, there are insuperable objections. As the rotatory engine is placed immediately upon the axle of the propelling wheels, there can be no springs between it and the wheels, so that every jolt would derange the machinery. The

weight of the engine placed on the axle would in turn reciprocate the evil by knocking the wheels to pieces. In the reciprocating engine these evils are prevented by the detachment of the engine from the axle, and the propagation of power through rods, wheels, or chains, to the propelling wheel or axis; and if any fault still remain in the principle of locomotive engines, it is the want of perfect detachment in the very respect which the introduction of the rotatory engine would render impossible.

In addition to all these obstacles which stand in the way of rotatory engines, it may be worth while to mention another circumstance of a practical nature which gives great superiority to the common steam-engine; we mean the facilities which it presents, and which the rotatory engine does not possess, for the attachment of the appendages that are indispensable to the functions of a perfect steam-engine. The subordinate parts of an engine which belong equally to a rotatory and reciprocating steam-engine are, an air-pump, a feed-pump, and a well-pump. These merely require to be attached directly to the beam of the common engine, and they are worked without the intervention of auxiliary mechanism, because the motion of the pumps is reciprocating, and the action of the steam is also in the common engine reciprocating; while, on the other hand, in the case of the rotatory steam-engine, it would be necessary to convert the revolving movement, by a crank or other more complex mechanism, into the very reciprocating effect which it is intended to supersede.

All these considerations, of a most important and immediate practical bearing, clearly prove, that although, in the most abstract and elementary theoretical view of the

subject, there be an apparent equality of effect in the rotatory and the reciprocating steam-engines, yet there are practical objections of an insuperable nature inherent in the very constitution of rotating mechanism, that prevents the possibility of rendering it more perfect.

III. It is lastly our duty to show that the common reciprocating crank steam-engine, not only does not possess the disadvantages attributed to it, but that it possesses certain very peculiar properties which may not have been hitherto clearly understood and defined, but which nevertheless do adapt it in so admirable a manner to the nature of steam and of solid matter, and to the necessary imperfections of all human mechanism, as to have rendered it triumphant in universal practice over every competitor.

1. It was long imagined that the transmission of power through a *crank*, or *bend*, or *handle* in an axle, was attended in the steam-engine with great loss of effect. In the opinion of such men as Smeaton, the crank was never likely to be used as the means of obtaining rotatory motion from steam; while it is this very crank that is, in our day, used alone and universally over all other methods, although a great variety of other methods have been successively invented, and finally abandoned for the simple elementary crank. Yet it is not without some show of reason, that objections have been made against the practical working of the crank. We admit that the argument was rather a staggering one, but the difficulty has lately been wholly removed.

The staggering fact, to which we refer, was this: it is given as stated by Dr Penneck of Penzance, Cornwall, in describing a substitute proposed by him for the

crank. "Some have considered a wheel as one-third more powerful than the crank, and others that no power is lost by the crank; but, confining myself to *practical results*, it appears from the report of the duty of steam-engines as done in Cornwall, and published by the Messrs Lean, that the performance of the crank engines bears no proportion to those in which no crank is employed." He then proceeds to show the advantages of his own engine, in which a ratchet-wheel is moved by an arm, always acting at the extremity of a radius, by which means he hopes to save the loss of power occasioned by the crank. The fact related by Dr Penneck was perfectly accurate. It had happened that the crank steam-engines, working expansively in Cornwall, had never given out an adequate effect. That the fault did not lie in the crank, but in other parts of the arrangement, is now apparent: it consisted in the want of proper adjustments to admit of favourable action in using the steam expansively. Arrangements for this purpose have, however, been at length accomplished, and crank-engines are now in Cornwall doing the same work as the average of those that have no crank. We have before us the printed reports of last year, stating the duty done by the crank-engines of Charleston and Wheal Kitty, constructed by Mr Sims. We have also before us indications of the *actual pressure of the steam on the cylinder*, as obtained by a very accurate indicator, applied in the course of the summer of 1837 by Mr Smith for Mr Fairbairn of Manchester, who visited the mines for that purpose, and has been kind enough to favour us with a copy of his diagrams and observations. We have thus the means of comparing the power actually exerted on the piston with the work done, and find the result of the

comparison to be, that *the work done is within ten per cent of being perfectly equal to the power employed.* Here, then, we arrive at this conclusion, that the utmost conceivable reach of improvement in the mechanism of the steam-engine, if it even attained to perfection, would not save more than a few per cents. That the crank engine is, therefore, as at present used, as near in practice to the perfection of mechanism as any thing we can hope to obtain, is, we think, satisfactorily explained.

2. The crank, as a means of converting the reciprocation of the piston of a steam-engine into continuous revolving movement, possesses certain singular and beautiful properties which distinguish it from every other means of producing that conversion, and which appear to be so perfectly adapted to the nature of steam and the constitution of solid matter, that we are indebted to it materially, though indirectly, for the very great advantages which we derive from the modern steam-engine as a source of mechanical power. Let us examine into the causes of this well-established practical superiority of the crank to all other modes of producing revolving motion. Let it be observed, that in the reciprocating piston, from which the crank derives its motion, the following things take place: the piston is to be put in motion in one direction, then stopped, then put in motion in the opposite direction, stopped again, and then its motion resumed in the first direction. We shall see how admirably the crank adapts itself to these changes; so that, while the piston with which it is rigidly connected takes every velocity between its maximum velocity and perfect rest, the crank goes forward with a motion perfectly regular and perfectly

unimpeded. The necessity of this gradual change from motion to rest, and a reverse direction of motion, is obvious. Matter in motion acquires momentum and cannot be stopped, but its impetus must be equally and gradually removed, otherwise these moving parts are subjected to concussion as if by the stroke of a hammer, and must either suffer injury or produce it; for, when in motion, matter requires a force to stop it equal to the force which gave it that motion. And, on the other hand, when brought to rest, matter cannot instantly be set in motion in the opposite direction without a stroke and concussion equally violent. To work smoothly, durably, profitably, and uniformly, matter must be put in motion by gentle gradations, beginning with a very gentle velocity, and gradually increasing in velocity like a body set in motion down an inclined plane, where, if it move one foot in the first second, it moves three in the next, five in the next, seven in the next, and so on: and in like manner in coming to rest, it must do so in the same gradual way in which an arrow shot from a bow vertically into the air loses its motion; for in the end of its course it moves seven feet in the first quarter of the last second of time, five feet in the next quarter of a second, three feet in the next, and only one foot in the last, and then subsides into rest at the instant before it recommences motion downwards, which it does in a manner perfectly similar. It is required, therefore, that while the motion which the steam gives off by the crank be uniform and continuous, the parts of the engine itself shall be allowed time to be alternately brought into a state of rest, without shock, concussion, or jolt, and equally, gradually, and gently be

again urged to their greatest velocity in the opposite direction. All this the crank effects with the most exquisite nicety of adjustment; it stops the piston when in motion as gently and softly as if a cushion of eider were placed to receive it; and after having brought it to rest, again begins and accelerates its motion, as gradually and gently, to the highest velocity in the opposite direction. An adjustment so perfect is only possible in such a relation as that which subsists between the circle of the crank and the axis of the piston. Now if we compare this mode of action with any of the substitutes for the crank, by which it has been proposed to gain uniformity of power, we shall find that in these it would be required that the transitions from rest to motion and from motion to rest should be instantaneous; and hence such arrangements, being soon disordered, have been abandoned. It will also be found that in rotatory engines it is necessary that the transitions and changes of arrangement, where these exist, are necessarily instantaneous, or if not, that steam is lost, or that the boasted uniformity of power is sacrificed.

3. The next property of the crank, as an elementary machine for the conversion of motion, is its remarkable power of reducing errors of construction, arrangement, and execution. It is one of the highest recommendations of a piece of mechanism, that any trivial errors committed in its construction shall not materially injure its efficiency; and that any slight derangement in its adjustment shall not be attended with immediate deterioration or aggravated injury; but that, on the other hand, the efficiency of the machine shall be consistent with such degrees of correctness in workmanship, and accuracy in adjustment,

and care in making use of it, as are consistent with the ordinary amount of intelligence and attention of ordinary workmen; and that the progress of derangement and necessary tear and wear shall be so gradual as to give timely warning of danger, and admit of ready repair and re-adjustment. The crank is precisely such a piece of mechanism. Errors in adjustment or construction of valves and other vital mechanism, are diminished in effect by the crank one hundred-fold; the changes of the valves, the essential part of the mechanism, take place only at the top and bottom of the stroke. Now at these instants the crank is on the "line of the centres," as it is technically called; and it is just in this position that a minimum of force is made to act on the crank; so that if the valves do not open with perfect precision, but either a little too soon, or a little too late, then will such error at that part of the circuit be of comparatively trifling consequence, because then the motion of the piston is so slight, that through an arc of twenty degrees of the crank it does not describe the hundredth part of that space; and the effect of any error committed within that range, will not affect the result in the crank by one hundredth part of its full amount.

In like manner, errors in management and errors arising from wearing, are reduced a hundred-fold in effect by transmission through the crank. It has frequently been to us matter of astonishment, to see at the mouths of coal-pits, mines, and quarries, mere remnants of engines, frail rusty old fragments of iron and wood so loose as scarcely to stand upright upon their bases, to see these superannuated drudges still performing heavy work to a very large percentage of their full power.

4. To these circumstances we may add, that it is to the possession of these properties that we may attribute the fact, that reciprocating engines are constructed of enormous weight in their moving parts, and of ponderous dimensions, without being thereby sensibly deteriorated in working. The crank acquires a slow motion at the commencement of the stroke, and an accelerated motion is thereby acquired in a manner equally gradual by all parts of the machine; and in like manner, at the termination of the stroke, it brings them to rest in a gradation so gentle and uniformly retarded, as again to receive from them much of the impetus which it had formerly communicated. The impetus, therefore, given to the reciprocating parts is only *lent*, not *lost*.

We have thus endeavoured to expose the nature of the fallacy under which they labour who imagine that the present steam-engine, as derived from Watt, is a machine which destroys or absorbs a large portion of the power it is designed to transmit, and who look to the rotatory engine as a means of increasing the amount of the power given out in useful effect. That the rotatory engines which appear day after day are not new, we show from the fact, that the five great classes which comprehend them all have already been invented and re-invented by upwards of a hundred individuals. That their inventions have been unsuccessful, is manifest from the non-existence of their machines in the daily use of ordinary manufactures. That the failures of these contrivances did not arise from defects accidental to the peculiar arrangements and contrivances of the engine, is rendered probable by the great variety of forms in which they have been re-invented, tried, and abandoned. That

they have not failed from deficiencies in the workmanship and practical details, is rendered still more probable by the circumstance of finding among the names of inventors those of the most eminent practical engineers. We have next shown, that in theory, the crank of the steam-engine in common use cannot, as has been supposed, be attended with a loss of power, as such loss would oppose the established doctrine of virtual velocities. It is also shown, from very simple and elementary considerations, that what appears to be lost in force is resumed in velocity; that in proportion as the mean force on the piston is greater than the mean force on the crank, in that proportion is the space described by the latter greater than the space described by the former; that the dynamical effect produced in a given time, is exactly in the proportion of the steam expended in that given time. And thus have we arrived at the conclusion, that the common reciprocating crank steam-engine has not the faults attributed to it in theory, and which the rotatory engines have been designed to remedy. We have next taken the practical view of the subject. In simplicity of parts, the rotatory engine has no advantage over the reciprocating piston; in difficulty of construction, the rotatory piston far exceeds the reciprocating engine: it is more expensive at the outset—it has more friction—it is more bulky and less compact—it is inferior in precision and uniformity of action to the crank-engine—and there is a radical fault inherent in the very nature of rotatory mechanism, from which it follows that the rotatory engine can never be rendered either an economical or a durable machine. We have further shown, that even if the rotatory engine could be made

economical and durable, its very nature renders it unsuited to the great purposes of steam navigation and inland locomotion; objects to which it has been considered peculiarly applicable. We deemed it an appropriate and instructive conclusion to our enquiry, to examine into the action of the crank, for the purpose of discovering what those remarkable qualities are, which have given to the crank of the common steam-engine its unrivalled superiority as an element for the production of circular motion, and a degree of perfection unattainable by any other mechanism. We have seen that well constructed crank steam-engines are daily performing duty which is within ten per cent of the theoretical maximum of possible effect—of absolute perfection; that this practical perfection arises from the simplicity of the crank, from its wonderful adaptation to the nature and laws of matter, and of circular motion in connexion with rectilineal motion—from its reduction of errors either in construction, adjustment, or management, so as to work well without the absolute necessity of greater intelligence, expertness, and precision, than belong to ordinary workmen—and from the compensating nature of the arrangement of its structure, by which it is accommodated in a remarkable degree to the necessary imperfections of all human mechanism.

ON STEAM-ENGINE BOILERS.

The construction of a boiler must appear so simple an arrangement of materials, as to require very little ingenuity or contrivance; a large enough boiler placed upon

a large enough fire being sufficient to generate any requisite supply of steam. Simple, however, as such an arrangement may seem, the best construction of boiler is a subject upon which very widely different and even opposite opinions are entertained by men of the greatest science and experience. There is perhaps no branch of practical art in which so much remains to be determined and improved, and scarcely any which science has done so little to advance. To follow servilely what has, in a given instance, been "found to answer," is the rule of the most sagacious mechanics, and the doctrine of the wisest authors. Those who have attempted to invent have commonly erred; those who have generalized have invariably been rash and unsuccessful, and their erroneous theories have led astray their followers, when they happen to have any.

The art of constructing steam-boilers is, we have said, in its infancy; but it is likely, we think, to make rapid progress. The construction of the boiler of the locomotive-engine, which every day performs what at a former period we should have termed impossibilities, exhibited a strikingly anomalous phenomenon, by which the attention of all men who thought upon such subjects was suddenly arrested: this little barrel of water generates as much steam in an hour, as would formerly have been raised from a boiler and fire occupying a considerable house. The frequent explosion of boilers, both here and in America, has also directed attention to the efficient construction of boilers. The patient experimental enquiry that has since been set on foot, must lay open the whole of the important parts of the question so thoroughly, and bring out the facts with such clearness and

precision, as to lead, by safe and rapid induction, to the general principles by which we may be able to predict the result of every supposed case, and deduce safe rules for the guidance of practical men in all circumstances. The investigation of the whole subject of steam-boilers, recently undertaken in America by the Franklin Institute, has already done much to settle many points of dispute. The publication of the reports of the American and English Governments on the explosions of steam-boilers, has elicited many valuable contributions to the stock of knowledge; the useful practical treatise of Mr Armstrong has given us an instructive view of the state of practice in the busy district of Lancashire; the treatises of Mr Wood and M. de Pampbour on Railway Locomotives; and the papers, in the Transactions of the Institution of Civil Engineers, on the statistics of Boilers and Combustion, have supplied and discussed a large collection of important facts, that will materially assist the future investigation of the best construction of steam-boilers.

During the first period of the history of the steam-engine, the danger of bursting the boiler, and the difficulty of making it strong enough to resist the internal force acting towards explosion, and also of making the joints tight against the leakage of highly elastic steam, formed the chief obstacles to the introduction of steam as a mechanical mover.

The first important point in preparing a steam-boiler is to secure strength, without unnecessary expense of materials. If we take the simplest form of vessel: suppose a simple rectangular water-tank—suppose the vessel on a small scale, made of sheet-iron, and soldered at the edges,

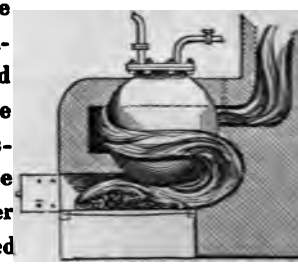
so as to form an air-tight box; then, by simply blowing into it, we shall manifest its weakness; for the sides will first of all bulge out, and, if the materials yield and allow the vessel to change its shape, it will at last swell into a globular form, with angular knobs upon it at the corners, from which pyramidal extremities, the globular parts, will finally be torn away with an explosion, which will, in all probability, take place long before the vessel has attained the shape mentioned above.

The globular or spherical shape was very early adopted, as one of greatest capacity, as a shape in which, the pressure at every point being equal, there remained no force tending to produce flexure, or destroy the equilibrium of strength and strain at any point. A fire was then lighted below the boiler, and the steam confined until the heat had raised it to the temperature required for the given pressure. This form was accordingly adopted by Hero, Savary, and others, as may be seen in the representations of their boilers, which we have given in the historical portion of this treatise.

It was soon found that a spherical boiler, being set upon an open fire, required an enormous consumption of fuel to raise a small quantity of steam, the heat being copiously radiated, not alone to the water in the boiler, but also in very great quantity to the surrounding objects, besides being rapidly carried off by the air. To surround the spherical boiler with non-conducting substances, and to keep the flame throughout its whole extent in contact with the surface of the boiler, so as to prevent radiation to surrounding objects, and also to diminish the size of the fire by making it wind round the boiler, were the

first steps towards improvement; and we accordingly find in the work of Dr Desaguliers the subsequent form of a boiler. Fig. 197 is a front view of the boiler *set* in a building of brick, a substance which is good as a non-conductor of heat, and calculated to withstand the destructive action of fire. A deep *ash-pit* lies immediately under the fire, which rests on a number of parallel iron *bars*, placed so close to each other as to prevent the fuel from falling through, and at the same time to admit between them the air requisite for combustion; and the *door of the furnace* being kept closed at all times, except when fuel is to be added to the fire, the whole of the matter of the fuel is in this way supplied with air, which passes up through the interstices of the bars. The flame, after having passed along the bottom of the boiler, winds in a corkscrew form around its sides, in contact with the surface of the boiler, in a spiral channel formed by the bricks, and called a *flue*, by which the smoke and hot air are at last conveyed into a *chimney*. A *damper*, as it is called, is formed by a small plate of iron, admitted through a slit into the opening where the flue joins the chimney; so that, by pushing this plate into the opening, the passage of the smoke out into the chimney, and consequently of the fresh air into the fire, may be obstructed, the combustion of the fuel retarded, and the too rapid generation of steam prevented. In this simple way, the attendant is enabled, by merely

Fig. 197.



pushing in or drawing out the damper, to regulate with great precision the generation of the steam. The pipe which conducts the steam to its ultimate destination, is called the *steam-pipe;* and there is another pipe necessary to the continued action of the boiler, called a *feed-pipe,* through which water may be made to enter the boiler, as it is evident that otherwise the water, being continually boiling off in the shape of steam, would soon leave the boiler empty; so that a constant supply of an inch of water for every foot of steam, or six gallons of water for every horse power, is required to enter the boiler through the feed-pipe.

The form of boiler next in simplicity to the spherical boiler is the cylindrical. From the facility with which a cylinder is made, it was introduced at a very early period. It stood upright, as in fig. 198, the fire being

Fig. 198.

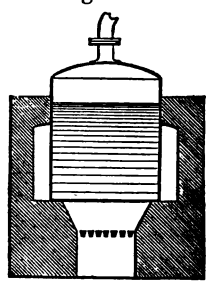
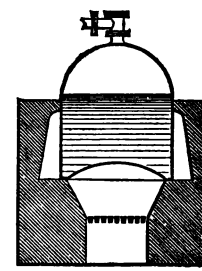


Fig. 199.



placed at the bottom, and the flue winding round that part of the sides covered with water. This form of boiler was found, however, to have the disadvantage of weakness in the bottom part.

For the prevention of these two evils, the cylindrical form of boiler was very soon modified and improved

by two opposite expedients, one applied at the top and the other at the bottom of the cylinder. The top being made hemispherical, possessed all the advantages of a spherical boiler; and the bottom being arched upwards, so as to present a large concave dome to the impact of the flame, this dome being sustained by the cylindrical belt round its spring, a very strong and extensive surface was obtained, as in Fig. 199.

In this cylindro-spherical boiler, it was found that the action of the flame on the upright round sides produced a very slight effect in raising heat. It was therefore desirable that the flame should be brought somewhat under the sides, by inclining them a little outwards. The boiler then assumed a form which has since become very common, and from its shape, has not inaptly been named the haycock boiler, fig. 200.

Fig. 200.

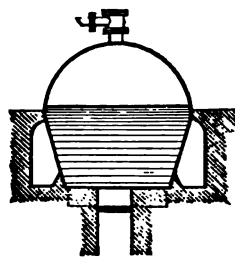
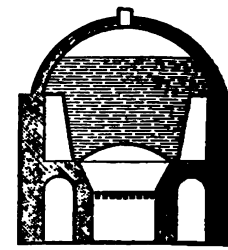


Fig. 201.



The same effect was next obtained in many of the boilers of Newcomen, in the way represented in fig. 201, so that the flame in the flues impinged upon a surface directly over them; the flues in this case forming a recess in the sides of the boiler, instead of being built around it by the brickwork alone. In process of time, boilers of much larger size came to be required,

and the spherical shape was found cumbrous and too capacious, that is to say, contained an enormous mass of water, which it required much time and fuel to heat to the boiling point before any steam could be raised. The diameter, also, of the boiler was so great when much steam was required, that the enormous dome became weakened. To make a stronger boiler, and one which should, at the same time, cover a large fire, the *waggon boiler* was introduced by Mr Watt; an oblong boiler, of whose form no better definition can be given than the descriptive epithet which forms its name. It closely resembles those long, heavily laden, four-wheeled waggons, which a team of six or eight horses may occasionally be seen dragging along with difficulty.

The waggon boiler is made of considerable length, and its transverse section, fig. 202, resembles that of the old cylindrical boiler.

Fig. 202.

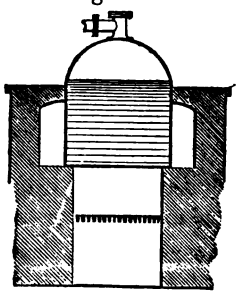
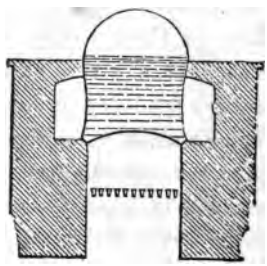


Fig. 203.



In this form the boiler was long made by Messrs Watt and Bolton. It was afterwards improved by hollowing inwards the sides, for the purpose of bringing them more immediately over the flame. Of this form of the waggon boiler, which is universally used at the present

by two opposite expedients, one applied at the top and the other at the bottom of the cylinder. The top being made hemispherical, possessed all the advantages of a spherical boiler; and the bottom being arched upwards, so as to present a large concave dome to the impact of the flame, this dome being sustained by the cylindrical belt round its spring, a very strong and extensive surface was obtained, as in Fig. 199.

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Fig. 200.

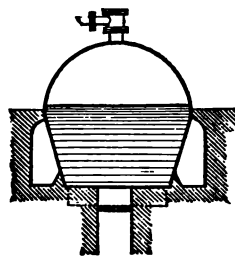

Fig. 201.

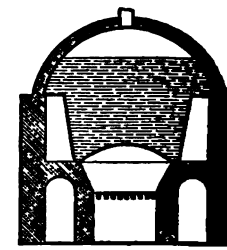

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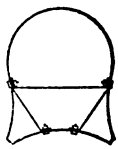
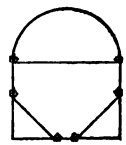
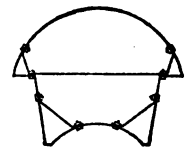
Fig. 205. Fig. 206. Fig 207.

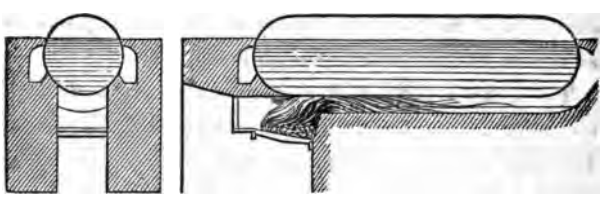






itself, is the object of that construction of cylindric boiler now much in use, especially where considerable pressure is used. It is certainly one of the cheapest, safest, and best boilers. A cylinder, figs. 208 and 209, perhaps thirty feet in length and four feet in diameter, with two hemispherical ends, is laid with its axis nearly horizontal; and below it, at one end, is placed the fire, enclosed by brick, as usual. The flame traverses the bottom of the boiler, beating directly upon its under

Fig. 208. Fig. 209.



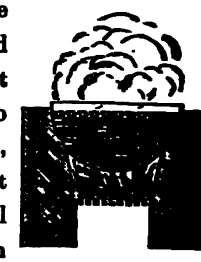
horizontal surface till it reaches the end furthest from the fire. The flame and hot air then return along the one side of the cylinder, being confined in a brick flue, and, passing along in front of the end which is over the fire, traverses the other side towards the chimney, which it enters after having thus traversed the length of the boiler three times, and applied its heat successively to every point of the cylinder which is covered with water. This is a boiler that requires no stays, and is valuable where room is not important. It contains much water,

requires much heat to raise its temperature after being cooled at night, and is very bulky. The Americans have adopted this boiler to a great extent. It was introduced among them by the ingenious Evans. It is generally of a smaller diameter than three feet, and has flat cast-iron ends of great thickness, which they call heads.

These boilers, the spherical, cylindrical, and waggon shaped, may properly be denominated the simple boilers. But some hundreds of kinds of boilers have been invented for different purposes; almost all of them designed to save either bulk, weight, or fuel. Some of these have been much more successful than others; and it is necessary to examine upon what principles any improvements attempted in boilers should proceed. In steam navigation, diminished bulk, weight, and consumption of fuel, are all objects of the first importance, as also in locomotive engines on land.

To make a little boiler generate a great deal of steam in a very short time, is a very difficult matter. Let any one take a common open caldron, or boiler, such as is used to boil a few gallons of water; suppose the vessel to hold 84 gallons of water, to be set on a fire so that 9 or 10 feet of its bottom surface are exposed to the fire; then he will find that he cannot turn more than about 6 or 7 gallons of water an hour into steam. By blowing the fire violently, this quantity may be exceeded, but with a great waste of coal: and it will require a very good chimney, with an

Fig. 210.



excellent draught, to produce even 6 gallons an hour in steam which is about the quantity of water an hour required to furnish steam for an engine of one horse power; 6 gallons being nearly one cubic foot.

Suppose, then, a greater quantity of steam is to be produced; how is that to be obtained? The answer is this: only by a larger boiler and a larger fire, acting on a larger surface. This general statement must be understood in the following way.

A larger boiler, calculated to generate more steam, does not exactly mean one which holds more water. It is found that the power of the boiler depends primarily upon the extent of its exposure to the action of the fire, or, as it is generally designated, the extent of heating surface. It appears that the heat cannot penetrate through the material of the boiler with more than a certain rapidity, and that the water evaporated over each square foot by the heat passing through, is not more than about $\frac{2}{3}$ths of a gallon in an hour; and so it requires some 9 or 10 such feet of heating surface to boil off 6 gallons, or a cubic foot of water, capable of producing one horse power in the steam-engine. Now, for every such foot of heating surface there will be a corresponding generation of steam; and a boiler having 100 square feet of surface exposed to the fire will be capable of evaporating 100 times $\frac{2}{3}$ths of a gallon of water an hour, being 60 gallons, and about 10 horse power. The extent of heating surface, and not the quantity of fluid contained in it, is the measure of the power of a boiler.

One great object of improvements in boilers has been, to increase as much as possible the extent of heating surface without increasing its general dimensions.

Fig. 211.

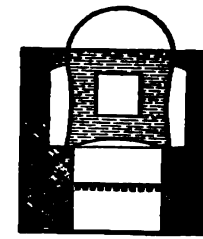
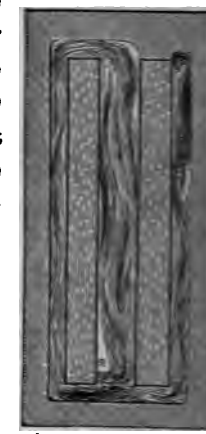


Fig. 212.



One very efficient mode of doing this, is by the adoption of internal flues. Thus Bolton and Watt have inserted a flue in the middle of the large waggon boiler, in the manner shown in figs. 211 and 212; so that, after the flame has passed along the bottom of the boiler to the further end, it returns along the flue in the middle of the water to the front, and then makes an entire circuit of the outside of the boiler before entering the chimney. Thus, in a boiler 6 feet wide and 8 feet high and 20 feet long, an internal flue 3 feet wide and 3 feet deep, along the whole length, adds about 240 square feet of surface to the boiler, without increasing the bulk of the room taken up by it.

The same plan has been extensively employed in cylindrical boilers, the flame and hot air being made to traverse a hollow tube or cylinder in the interior of the boiler: sometimes several such flues have been used, and these multiflued boilers are now in great repute. Several modifications are given in the figures. The small internal pipes or cylindric flues, surrounded with water traverse the whole length of the boiler, and expose a greater quantity of surface of water to the action of heat, in proportion as the tubes are small and numerous. These

Fig 213.

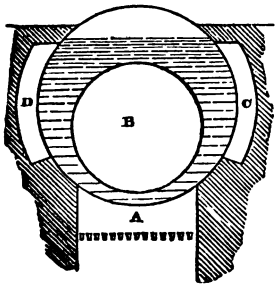
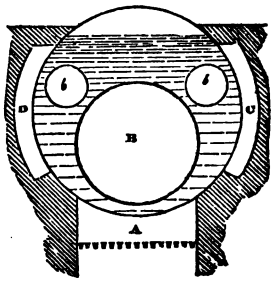


Fig. 214.



tubular-flued boilers are at the present day extensively used. They economize space, and, with a small exterior surface of boiler, generate a large quantity of steam. They are much used in Cornwall, in marine boilers, and in locomotive boilers.

In these boilers a large surface is still exposed to the cold air, and the brick-work in which the fire is placed radiates off a considerable portion of heat, which is lost. To remedy this evil, the furnace has been so contrived that the fire is in the inside of the boiler. This was probably done for the first time by Smeaton, who succeeded in producing almost as high a proportion of steam from fuel as engineers of a more modern date. His portable-engine boiler is represented in figs. 215, 216. The interior of this hay-cock boiler contains a hollow ball of cast-iron, in which the fuel is burned. Air enters by an aperture at the bottom, a large cast-iron pipe leads through the water to the door, and another pipe in the opposite direction passes through the water, conducting the products of combustion to the chimney, immediately round which is introduced the fresh supplies of cold water for replenishing the boiler.

Fig. 215.

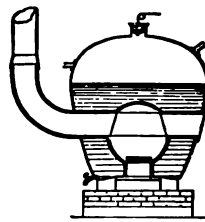
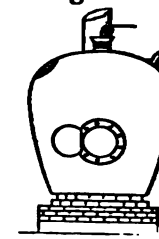


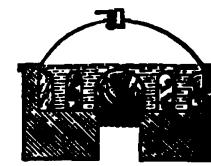
Fig. 216.



But a much better boiler than this, and one indeed which might bear comparison with many boilers of the present day, is one given by Mr Farey as the invention of an unknown author. In the centre of a large old-fashioned hay-stack boiler, figs. 217, 218, is placed a large round furnace, from which there passes a simple rectangular flue, winding round and round the boiler in spiral circuits till it reaches the outside, and thence passes to the chimney.

Fig. 217.

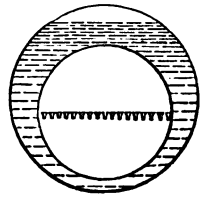
Fig. 218.



In the same way it has often been provided that the furnace should be in the interior of a cylindrical boiler, by placing another cylindrical tube of large dimensions in the interior of the outer case, as in fig. 219, to serve at once as furnace and flue. This was probably first done by Trevithic, the advocate of high-pressure engines in this country.

To the great central flue there have been sometimes added lateral flues on each side, for the return of the

Fig. 219.



products of combustion, fig. 220. Thus, again, this internal flue has been made elliptical, fig. 222, a dangerous and weak form.

Fig. 220.

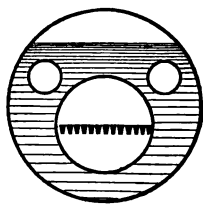
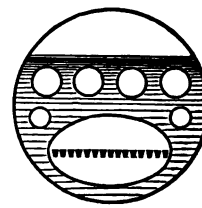


Fig. 221.



It is one of the faults of the boilers that have their fires in the internal tubes, that the ash-pit and interior of the furnace over the fuel are so confined, as to prevent that perfect combustion of fuel which may be obtained by a deep ash-pit, a large expanse of fire-grate, and a deep and wide furnace. These evils may, in some measure, be obviated by an internal flue of large dimensions; but this very large one is extremely dangerous, and liable to explosion. The evil has been remedied by the following species of boiler, figs. 222, 223, where the fire is still surrounded by water, and gives ample room for the most perfect combustion.

Fig. 222.

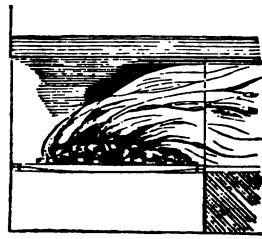
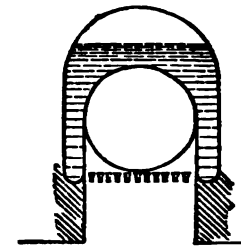


Fig. 223.



In this species of boiler, the tube opens out at the front, so as to leave a semicircle or a semi-cylinder above the fire, and two vertical spaces, or "water legs," as they are called, which cover the fire on both sides; thus obstructing the heat that would otherwise pass away into the brick building, and at the same time covering a large and wide space of furnace bars, a deep ash-pit, and so ensuring adequate combustion. The internal surface of this boiler has been still further increased, by substituting for this single tube a number of smaller ones six inches in diameter, as in figs. 224, 225.

Fig. 224.

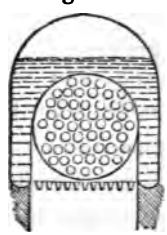
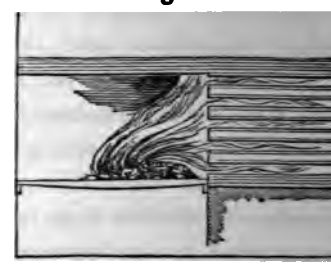


Fig. 225.



After passing through all these tubes, the flame and hot gases again return along the bottom and sides on the right of the boiler, and pass back on the other side to the chimney. A form of boiler similar to this is much

used in Lancashire, and is called the Butterly Boiler, figs. 226, 227. It has the large internal flue, but wants the fire legs, and in this respect is inferior to the former.

Those boilers, already described, are the practical forms in use among intelligent engineers. The varieties of boiler that have been invented, amount to some hundreds. The Patent Records of the present day teem

Fig. 226.

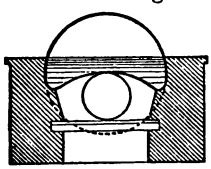
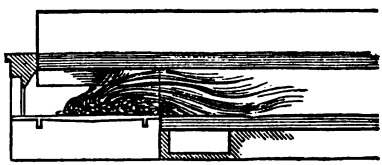


Fig. 227.



with new and improved boilers; and yet it is a matter of constant complaint with engineers, that no great improvement has ever been made in boilers, but that as satisfactory results have been obtained from plain, simple boilers, of the kind used half a century ago, as from the modern and most complex forms.

The conclusion to be drawn from all that has been attempted or achieved in boilers is, we believe, the following: that there exist certain limits prescribed by the constitution of fuel, the nature of metals, and the properties of water and steam, which cannot be exceeded without incurring evils that greatly overbalance the partial gain. The best boilers that have ever existed have been those in which a large number of principles have been applied, and so adjusted in relation to each other as to gain the maximum, not of any one property, but of all the valuable properties, each in the degree of its individual importance. The first cost of the boiler must not be rendered too great, or that will neutralize the economy

of using it: the space to which it is confined may be as small as possible; but if that be produced by intricacy of construction, the loss may surpass the advantage. Then, again, if complex and confined, it may be impossible to cleanse or to repair the boiler; and therefore it must be remembered, that, unless easy access can be gained to every part of a boiler, and of its flues, that boiler will soon become totally useless. Then it is further demanded of a good practical boiler, that, if one part should be damaged or give way, the whole should be so constructed that the damage done to that part must not endanger the rest. An extensive heating surface is to be obtained for economy's sake; but that large surface must at the same time remain unimpaired to resist bursting; a property to a certain extent inconsistent with extensive surface. The surface which is thus spread as widely as possible, so as to apply the fire to the water through every part of its mass minutely and in great subdivisions, if extended beyond a certain degree, will not have over it a body of water capable of conducting heat from it with the rapidity adequate to the rapid generation of steam, and to the preservation of the intensely heated metal from the destructive action of the fire. Then, again, it is desirable to have long and tortuous flues, to extricate as much heat as possible from the fuel and the products of combustion; but these, by their very length, may interfere with the draught of the chimney, so as to diminish the efficacy and vigour of the combustion of the fuel, and produce loss instead of gain. Thus it happens that the whole question of boilers is an exact and judicious combination and adjustment of parts, so as to obtain each of these many points in that degree which is most

advantageous for every one of the other qualities, and of all of them together. The question is a practical one of no common difficulty.

It is principally by the collection of facts, of accurately recorded statistics of boilers, of the practical experience of the most eminent engineers, that we can gather data for the solution of the question of the best boiler. We are not without such data, although it is much to be regretted that they are not so abundant as we should wish. We shall now examine the various points in the structure and functions of a boiler in a simple succession.

The materials of which a boiler should be formed, have been a subject much discussed. Copper, iron, brass, cast-iron, lead, and even stone, have been employed. Boilers of steam-vessels are frequently made of copper. Many steam-boilers have been made of cast-iron, and have lasted long, and been very efficient under careful management. Wrought-iron-plate boilers are very common in this country; and in America have been much used, with cast-iron ends or heads of considerable thickness. The boilers of locomotive engines have the interior, which is exposed to the direct impact of the flame, formed of copper, and sometimes partly of brass; the exterior of the boiler being wrought-iron. Cast-iron boilers were extensively used under Mr Smeaton, towards the end of last century; and when used with care, were employed with advantage where fuel was plentiful, from their cheapness. A stone exterior jointed with cement, the interior being copper, where subject to great heat, and when the steam has scarcely any greater pressure than the atmosphere, has also been employed; and a dome or cupola of lead was often seen, in earlier times, when

the art of working iron-plate was less common than it is now, forming the cover of the antiquated hay-stack boiler, which, in these times, the "waggon" of Watt has almost entirely removed out of use.

Copper is the best of all substances for steam-engine boilers, in a mechanical point of view. That it is not best in a mercantile point of view, is proved by the almost universal use of wrought-iron boilers. Yet it is difficult to see why this should be the case, if we remember that copper lasts for ever, and is worth, when old, nearly two-thirds of its first cost, besides being a much better conductor of heat, and so saving fuel and space. The labour, too, of making a copper boiler is no greater than an iron one. The relative value of these materials for boilers may be stated thus:—

The efficiency of a copper boiler in generating steam, is to that of iron as .	3 to 2
The cheapness of equal weights of copper and iron boilers, are as . .	30 to 130
The value of old materials diminished by 15 years' interest, is . . .	4 to 3
Durability, ...	5 to 1
	30 to 13

The combination of all these ratios is in favour of copper; and if we add the trouble of replacing the new iron boiler, and detaching it from all its connexions, five times for once in the case of copper, the scale still further preponderates on the same side. We must look, therefore, for the explanation of the general use of iron to the state of mercantile affairs, and the value of money in

a commercial community. It proves that a certain loss, within 15 or 20 years, in a proportion of 12 to 1, is considered preferable to an original expenditure of four times the amount of capital; showing either that the price of money is too high for such an investment, or that the contingencies of mercantile life are too great to allow the risk of so large a sum as the value of a copper boiler for the period required to reimburse the proprietor. Rich governments and individuals have not failed to profit by this knowledge; but it may be noticed of a government which considers its tenure of office insecure, that it does not furnish even its war-steamers with copper boilers, as that would involve the expenditure of a large sum by which their successors would profit. So also the man who is shortened in means, but hopes to be rich enough by the time one boiler is done to get a new one; or who does not know whether he shall be solvent so long as to see the boiler out; or who, at any rate, cannot spare so much money at once—procures at once the cheapest boiler he can; and finds, as usual, that in a short time the expenses of coal and of repairs have drawn from him a heavier than the usurer's percentage. All this applies more peculiarly to steam-vessels.

Another peculiarity of copper is the greater safety which arises from the uniformity of its texture. It is scarcely possible to account for the singular differences of sheets of iron that have passed nominally through the same processes of manufacture. One plate will become deteriorated by heat in half the time of another apparently identical. The parts of the same plate are frequently heterogeneous. The consequences of this heterogeneity are serious, and sometimes destructive: a single plate in

a series gives way, and, having broken the chain of connexion, the whole fabric is destroyed; or a latent crack developes itself in the place most difficult to restore; or one plate, or a part of it, is burnt through when all the rest remains sound. All this tells in favour of copper. The matter of the copper is very nearly homogeneous: its durability is nearly uniform if it is not made too thick. We have examined the part of a copper boiler exposed to most intense heat after years of action, and found, when the soot was cleared away, the smooth shining surface, produced by the rollers in the process of manufacture, remaining as perfect as the day after the boiler was started. In this case the metal was no more than one-eighth of an inch thick.

There are some forms of boiler for which copper is less suitable than iron. The strength of copper to resist flexure is not nearly so great, especially at high temperatures, as that of iron. A copper boiler must therefore be well stayed, and if there be round, or any other unstayed flues in the boiler, they cannot be of more than a foot in diameter without incurring danger; they will readily collapse or bend. This caution in regard to copper being given, it may be unhesitatingly recommended in point of safety, durability, and ultimate economy.

In the treatise on STEAM, we have already introduced our readers to the important experimental researches of the Commission of the Franklin Institute in America, concerning the structure, phenomena, and explosions of steam-boilers. We shall, in another place, present the results of their investigations of the causes of explosion. But there is a branch of the investigation undertaken

by the committee, which is of importance to our present enquiry. It regards the strength of the materials of steam-boilers; a subject not before satisfactorily examined; and relates more immediately to the effect of high temperatures on the cohesive attraction of the particles of metals; an enquiry essential to our knowledge of the manner in which the known strength of metal, when cold, may be altered when, in a boiler, it is subject to the action of a fierce fire. The sub-committee to whom this subject was intrusted, were men of great practical skill and eminent scientific attainments. Professor Walter R. Johnson, Benjamin Reeves, Esq., and Professor A. Dallas Bache, were the members to whom the enquiry was committed; and it has been carried on with a degree of judgment in its arrangements, and of precision in the experiments, which warrant our implicit confidence in the results, and deserve our sincere thanks for the valuable additions made to our knowledge of this important and difficult subject. The importance of the branch of enquiry committed to these gentlemen, may be judged of from the following statement of its principal branches.

1. What is the absolute tenacity of rolled boiler iron at ordinary temperatures, and how great the irregularities to which it is liable?

2. A similar determination for copper boiler plates.

3. What effect is produced on the tenacity of these boiler plates by change of temperature?

4. What is the effect produced on the tenacity of iron by various processes of manufacture, such as wire-drawing, hammering, or rolling into bars or rods?

5. What are the comparative tenacities of boiler plate made from different mixtures of crude iron and from refined irons?

6. What is the comparative value of sheet iron manufactured by the processes of puddling, blowing, and piling respectively?

7. What is the effect of piling into the same slab, iron of different degrees of fineness?

8. What is the comparative tenacity of rolled iron in the longitudinal, diagonal, and transverse directions of the rolling respectively?

9. What is the influence of frequently repeated heating on the plates of a boiler?

10. What relation exists between the force that will produce a permanent elongation in boiler plate, and that which will entirely overcome its tenacity?

11. What amount of elongation may the several kinds of metallic plates undergo before fracture?

12. What is the effect of rivets on the strength of a boiler?

These are some of the many important subjects of experiment undertaken by the committee. They have discharged the duties devolved upon them in a manner which is highly honourable to themselves, and which reflects great credit on the institution and the country that has sent forth into the world so valuable a contribution to practical science. We regret that the limits of this treatise will not permit us to enter into the experimental details and subsidiary enquiries connected with the extensive and laborious investigation; details which are always ingenious and instructive, and will amply repay the minute study of the mechanical philosopher or engineer

as a valuable body of experimental truth. But, although we cannot convey to our readers the pleasure we have enjoyed in the perusal of these interesting records, we should do them and our subject injustice did we omit to convey to them the general conclusions which have been obtained.

Strength of Copper Boiler Plates.—The experiments upon this subject were very numerous. 32° being taken as the standard, it was found that the increments of heat always caused a diminution of strength. Thus, a strip of copper, capable of carrying 10,000 lbs., was only capable of carrying 7,500 lbs. when heated to a temperature of 500°; while at 820° the same bar could support no more than a tension of 5,000 lbs, and at 1200°, a visibly red heat in day-light, no more than about a tenth part of the strength remains. By these experiments the law which connects the diminution of cohesion with the increase of temperature has been accurately determined, and it appears conformable to the following simple expression,

$$\left(\frac{t'}{t}\right)^3 \quad \left(\frac{d'}{d}\right)^2$$

when

$$\text{Log. } d' = \frac{3}{2}(\text{Log. } t' - \text{Log. } t) \text{ Log. } d$$

by means of which the diminution of strength having been ascertained for one temperature, it may be found for every other according to the following rule. From the logarithm of (t') the temperature (reckoned from 32°) of the diminution sought, subtract the logarithm of a given temperature, (t) and multiply three halves of the remainder by the logarithm of the known diminution (d) of strength at the latter temperature, and the

product is the logarithm of the required diminution at the temperature assigned.

The following table exhibits the close accordance of the experiments with this law.

Table of Diminution of Strength of Copper Boiler Plates when heated. Their standard strength at 32°, being 32,800 lbs. per square inch.

	Temperature above 32°.	Diminution of Strength.		Temperature above 32°.	Diminution of Strength.
1	90°	0.0175	9	660°	0.3425
2	180°	0.0540	10	769°	0.4398
3	270°	0.0926	11	812°	0.4944
4	360°	0.1513	12	880°	0.5581
5	450°	0.2046	13	984°	0.6691
6	460°	0.2133	14	1000°	0.6741
7	513°	0.2446	15	1200°	0.8861
8	529°	0.2558	16	1300°	1.0000

We are, therefore, warranted in admitting the conclusion, that the square of the diminution of strength varies with the cube of the temperature.

Hence we learn, that between the temperature of freezing and boiling water copper loses 5 per cent of its strength; that at 550° it loses about a quarter of its strength; at 850° the half of its strength; and at 1330° loses all its strength, becoming a viscid, granular, soft, incohesive, substance; although it does not actually melt until it attains nearly 2000°. These phenomena in copper are strikingly at variance with the phenomena exhibited by iron at the same temperatures.

In this substance the remarkable anomaly was discovered, that the additions of heat, instead of weakening the metal, as we should have expected, and as was found to be the case with copper, actually increased its strength,

so that iron plate at 550° above the freezing point was 16 per cent stronger than when cold. After this point the strength began to diminish rapidly, so that this point appears to be the temperature of maximum strength. It was assumed as the standard strength, on both sides of which the strength was found to be diminished both by heat and cold. The strength diminishes rapidly with increments of temperature, after passing the maximum at 570°: thus,

At 32° to 80° the tenacity was = 56,000 lbs. or 1-7th below its maximum.
At 570° —— = 65,500 lbs., the maximum.
At 720° —— = 55,000 lbs., the same nearly as at 32°.
At 1050° —— = 32,000 lbs., nearly ½ of the maximum.
At 1240° —— = 22,000 lbs., nearly ⅓ of the maximum.
At 1317° —— = 9,000 lbs., nearly 1-7th of the maximum.
At 3000° iron becomes a fluid.

The following is a table of a series of these experiments.

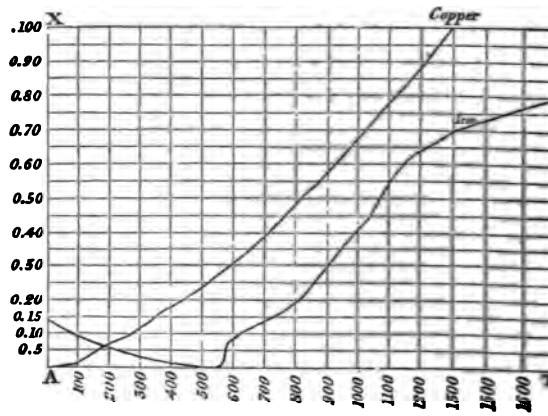
Table of Experiments on Iron Boiler-Plate at High Temperatures; the Mean Maximum Tenacity being at 550° = 65,000 lbs.

Temperature observed.	Diminution of Tenacity observed.	Temperature observed.	Diminution of Tenacity observed.
550°	0.0000	824°	0.2010
570	0.0869	932	0.3324
596	0.0899	947	0.3593
600	0.0964	1030	0.4478
630	0.1047	1111	0.5514
562	0.1155	1155	0.6000
722	0.1436	1159	0.6011
732	0.1491	1187	0.6352
734	0.1535	1237	0.6622
766	0.1589	1245	0.6715
770	0.1627	1317	0.7001

The law of variation of the strength of iron and of

copper by temperature may be easily illustrated by the following curves, of which the horizontal ordinates are temperatures, and the vertical abscissæ are diminutions of strength.

Fig. 228.



The temperatures are measured from the origin A towards T. The total strength being = AX = 1000, the diminutions of strength are represented by the fractions of A X measured from A towards X. These curves represent to the eye very distinctly the characteristics of the metals. The line for copper, rising from zero at A, shows, by continual recession from its maximum A A the continual and regular diminution of strength by increased temperature according to the law already stated. The line representing the iron, on the contrary, having its origin 15 per cent above A, descends and shows an increase of strength until it reaches a maximum about 500°, whence it suddenly rises, showing a very rapid diminution of strength up to 1000°, when again it

changes, turns outwards having a point of inflection beyond which it may be carried to a great distance, while at last it becomes liquid between 2000° and 3000°.

The next branch of the enquiry was, how the strength of iron is affected by the mode of its manufacture, and by the different states in which it is used, as in bars, in wire, or in plates, produced by hammering, drawing, or rolling. The following are the results of several experiments on the tenacity of different kinds of iron, at ordinary temperatures.

Iron Wire, diameter	0.333	84,186 lbs.
	0.190	73,888
	0.156	89,162
Russian Bar Iron,		76,069
English Cable Iron, hammer-hardened,		71,000
English Cable Iron,		59,105
Lancaster Co. U.S.		58,661
Centre Co., U.S.,		58,400
Swedish Bar,		58,184
Salisbury Com., U.S.,		58,009
Tennessee Bar, U.S.,		52,099
Slit Rods,		50,000
Missouri Bar Iron,		47,909

No. 1. Pig iron of a white fracture produces the most cohesive bars.

No. 2. Pig iron of a lively gray fracture produces bars inferior to No. 1 by $1\frac{1}{2}$ per cent.

No. 3. Pig iron of a dead gray fracture produces bars inferior to No. 1 by 2 to 3 per cent.

No. 4. Pig iron of a mottled fracture produces bars inferior to No. 1 by 5 per cent.

A mixture of all the kinds produces bars inferior to No. 1 by 5 to 10 per cent.

The difference between the strength of boiler-plate, cut lengthways and across, was found to be about 6 per-cent in favour of the longitudinal over the crosscut.

Stripes cut longitudinally sustained 63,947 lbs.
Stripes cut transversely sustained 60,176 lbs.
Stripes cut diagonally sustained 53,925 lbs.

The specific gravity of iron boiler plate was found to range from 7.7922 to 7.6013, and to be at a mean value 7.7344.

The effect of repeated piling and welding was found to be a great increase on the strength of iron. The iron given in the preceding table, from the Centre Company's manufactory, whose strength when rolled amounts to 58,400, was found to be so much improved by piling four bars and welding twice, as to support a mean of 59,247 lbs. and to be so homogeneous that the highest did not differ from the lowest results by more than 3.4 per cent in the different specimens. Simple welding twice without piling, gave a result of 58,787 lbs.

It has been thought that by welding together different kinds of iron of different degrees of fineness, and then rolling it out, a valuable boiler-plate might be obtained. This was tried, and the highest result gave only 40,600 lbs

The weakening effect of riveting is thus calculated from these experiments, being a diminution on the whole of $\frac{1}{3}$ of the original strength.

Strength of the stripe without riveting, . .	9290.
Strength of the remaining metal, deducting rivet-holes, ...	+ 5662

Diminution of strength by rivet-holes, . . — 3628
Strengthening effect of rivets, . . . + 679.

The effect of use and long exposure on the strength of boiler iron was found to be a great diminution of its strength, none of the specimens coming up to 50,000 lbs.

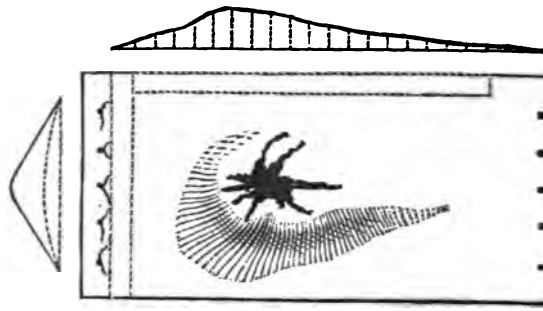
The effect produced by the accidental overheating of a boiler, was found to be the permanent reduction of its strength from 64,000 or 65,000 lbs., to 45,000 lbs. per square inch, being about $\frac{1}{3}$d of the original strength.

The permanent extension produced on iron plate by weights much less than are required finally to overcome its cohesion, was a subject of careful examination. The extension began to take place in general when $\frac{2}{3}$ths of the breaking weight were applied, and sometimes when only $\frac{2}{3}$ths had been applied. The total extension varied between $\frac{1}{10}$th and $\frac{1}{16}$th of the total length, and was greater in the longitudinal than the transverse direction of the bar.

The following diagram of a fracture is highly instructive. The elongation transversely is $\frac{1}{10}$th of the original dimension, and the curve is $\frac{1}{7}$th longer than the chord. The longitudinal direction of the fibres is in the line of the shortest dimension. It is evident that the diminution of the thickness, previously to fracture, must have greatly weakened the plates of the boiler. This boiler plate was taken from that part of the boiler immediately over the fire, and had burst where sediment had collected, and excluded the water from contact with the boiler, so as to allow it to get overheated.

It is evident that the diminution of area at the point of fracture, which accompanies this stretching of the plate before fracture, must weaken the plate very greatly when

Fig. 229.



it is exposed to strains that stretch it much beyond its initial length, this strain being about half the breaking strain due to the original thickness. This constriction or thinning out of the plate is observed to take place much more in thickness than in breadth, and to amount in iron to about 16½ per cent of the whole area. It is remarkable, that the constriction was found less in heated than in cold specimens of iron, a result the reverse of that which we should have anticipated. The fractures at high temperatures were found to take place suddenly, and the surfaces of fracture presented appearances altogether different from those exhibited at low temperatures; the peculiarity of the fracture at high temperatures being, that the section is smooth and flat instead of jagged, fibrous, and irregular, and that it takes place directly across the plate, and tapering off at an angle of 45°; so that the separate fragments resemble "the edges of two mortising chisels." One result which we deduce from the American investigation is, that boiler iron cannot safely be trusted with a greater pressure than ⅓th of its standard maximum cohesion. Such are some of the

valuable facts elicited by this transatlantic investigation. The experiments should be repeated in this country upon the different species of our own iron; and we have no doubt the subject will be taken up by some of those gentlemen who have prosecuted valuable researches on the strength of metals; into which, however, they have not yet introduced the element of high temperature.

The increase of the strength of iron, with the increase of its temperature up to 570°, is a remarkable anomaly which should incite us to examine other metals, and metallic alloys, in a similar manner, for the purpose either of resolving this phenomenon into some general law of corpuscular force, or of setting it aside as a characteristic and distinctive property of that singular metal. To the practical man, this discovery is of importance, insomuch as it has shown him a quality in iron, as a material for boilers, which may weigh strongly with him when he hesitates in choosing.

The comparative value of copper and iron boilers is materially affected by this enquiry. The great advantages of copper are its durability, its high conducting power, and the value of the old materials. It is by no means so strong as iron, being, when cold, $\frac{5}{3}$ths of the strength of iron, and at 500° only about $\frac{3}{8}$ths of the strength of iron. But thin iron decays so rapidly, that its strength to-day is no criterion of its strength to-morrow: it decays so rapidly, especially with the salt water of steam vessels, that its very strength at first is necessarily followed with subsequent danger; for an iron boiler having once borne a great pressure with impunity, will afterwards, when the rapid but unseen decay has insiduously eaten through the metal, be again

subjected to the same ordeal by which it had been formerly proved; and although under apparently the same circumstances, it may yield to the strain, and produce the distressing consequences of a violent explosion. It is time alone, then, that is the great enemy of iron boilers, while the integrity of the copper will continue unimpaired for a quarter of a century. On the whole we find that the following general result should limit our faith in the materials of boilers :—

Standard strength of boiler plate, . .	55.000.
Strength after riveting, ...	$\frac{2}{3}$.
Strength after heating and cooling in use, .	$\frac{2}{3}$.
Strain of permanent extension, . . .	$\frac{2}{5}$.

Greatest practical strength $= \frac{2}{5}$ of $\frac{2}{3} + \frac{2}{3} = \frac{8}{45} = \frac{1}{6}$ nearly.

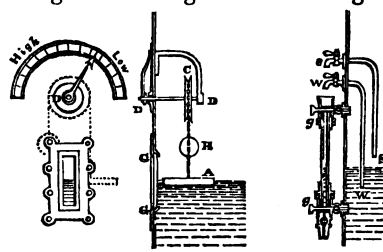
The greatest practical strength being $\frac{1}{6}$th of the absolute cohesion, and the greatest practical strength, to prevent explosion, being four times more than any boiler should be ordinarily worked at, we have $\frac{2}{45}$ or $\frac{1}{22}$ of the standard strength of boiler iron, as its ordinary working pressure; 2,500 lbs. of extension on each square inch of cohesive action may, therefore, be assigned as the safe working strain of iron boilers.

To a steam-engine boiler there are many appendages, contrived for the purpose of facilitating the regulation of the quantity of fuel or of water, the intensity of combustion, the elasticity of the steam. One of the most simple and essential of these is a water-gauge. Water-gauges are of three kinds, glass-gauges, stopcock-gauges, and float-gauges.

The glass-gauge is of two kinds, plane and tubular. A

plane glass-gauge consists simply of a small window in a boiler, of very thick glass, inserted at the place up to which the water should rise in the boiler. The tubular glass-gauge is a small pipe of glass about half an inch in the internal diameter, and an inch and a quarter in thickness. It is placed on the outside of the boiler, and communicates at the top and bottom by stopcocks with the interior of the boiler; the higher stopcock enters the boiler among the steam, a little above the upper surface of the water, and the lower stopcock enters a little below the surface of the water, so that the water, standing in the glass tube on the same level with the water in the boiler, shows itself in the glass tube to the attendant. These two gauges are shown in the accompanying drawings.

Fig. 230. Fig. 231. Fig. 232.



In figs. 230, 231, G is the window of very thick glass, set in a brass frame with a cement of red and white lead, after which, the frame is firmly bolted on the front of the boiler, at the aperture to which it is fitted. *gg*, fig. 232, is the tube glass-gauge, communicating with the water below and the steam above. There are shown in the same figure two other kinds of gauges. W*w* is a tube open at both ends, regulated at the external termination by a stop-

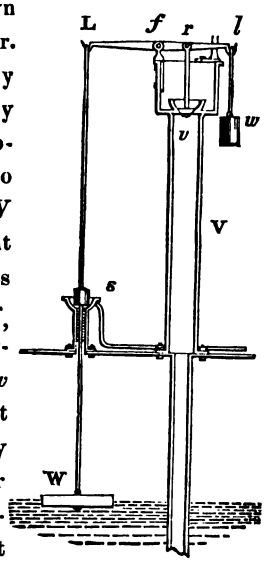
cock, but passing into the boiler, so that the other end descends below the surface of the water in the boiler. Another gauge-tube S*s* is of similar construction, and is placed higher up, so that the end S is open in the boiler among the steam. By this means the engineer has it always in his power, on opening these cocks successively, to determine whether there be an excess or deficiency of water in the boiler; for the orifices of the tubes in the inside of the boiler are adjusted in such manner, that when the water is at the proper level, it covers the orifice of the lower one, but does not reach the orifice of the upper one. In this state steam will issue from the upper pipe, and water from the lower pipe; but if it should be found that water issues from both, the water is too high, and if steam from both, there is too little water in the boiler. Another species of gauge is also shown in figs. 231, 232. It consists of a float A resting on the surface of the water in the boiler: to this is attached a chain, which passes over a pulley C, and carries at its other end a counterweight R. The pulley is fixed on an axle DD, which passes through the boiler and carries on its outer end an index. The index shows, by means of a dial-plate, the state of the water in the boiler.

By these means, a careful attendant may always ascertain the state of the water in the boiler, with sufficient ease to enable him to regulate the supply of water thrown in, or the feed of the water to the boiler, so as to replace, with cold water, the deficiency occasioned by the continual conversion of the water into steam. But if by any cause the attention of the keeper should be directed from the examination of the state of the boiler,

it will gradually become emptied, and will either be exploded or burned out, from being made red hot. Various contrivances have been attempted for the purpose of rendering boilers automatic; so that the very fact of the water becoming low in the boiler should of itself be the means of furnishing a fresh supply. The manner of accomplishing this is somewhat different in different circumstances; but the following methods are the most common and the best.

A self-regulating feeding apparatus may be adapted to the boiler of a low-pressure steam-engine, in the following simple way. The water that is to feed the boiler, is to be conducted into a reservoir *v r*, of some 18 inches diameter, having a long pipe to lead down from it to the bottom of the boiler. The top of this pipe is closed by a tapered plug which hangs by the rod *v r*, from a lever supported at *f*, and having two weights, one at either end, W and *w*. The larger weight W, of stone or cast iron, rests on the surface of the water in the boiler, and is counterpoised by a smaller weight *w* in such a manner, that a part of the weight W is sustained by the water; therefore, whenever the water in the boiler falls below the proper point, the weight W preponderates, the arm L of

Fig. 233.



the lever is pulled down by the wire W L, which passes steam-tight through a stuffing box at *s*, the end of the lever *l* ascends, and the valve *v* being withdrawn, allows the water to descend through the open end of the pipe, and replenish the boiler; and after a time, when the supply has become sufficient to raise the water to its proper level, the weight W, and the end L of the lever, are raised, the opposite end *l* is depressed, and the valve *v* once more closed, until a further supply has become necessary, when it is given again in the same manner.

This self-acting valve is sufficiently efficient when the boiler is of low pressure, or when the reservoir is more than two feet two inches high above the surface of the water for every pound of pressure per square inch of the boiler. But it very often happens that the boiler is fed with cold water in a different manner: a force pump is attached to the steam-engine, by which each stroke of the engine sends back into the boiler a quantity of water equivalent to that which has been evaporated out of the boiler in forming the volume of steam which has given to the engine motion through that stroke by which the pump has been impelled. Now, if the size of the pump were accurately proportioned, so as to replace in the boiler at each stroke the precise quantity of water evaporated from it in the same interval of time by the engine, it is evident that no further provision for adjustment would be necessary. This quantity is exactly one cubic inch of water for each cubic foot of atmospheric steam given to the engine, or one cubic foot = six gallons per horse power per hour. But the evaporation of the water to a steam-engine is not thus uniform, nor so easily determined.

The variations of intensity in the fire cause steam more or less dense to pass over into the engine; the steam now raises the safety-valve and escapes into the air, and now falls below the standard; the boiler, now tight, and again allowing water and steam to leak through its joints, consumes a greater or a less quantity of steam; and thus, even with this automatic supply, there is required a regulating or governing power. A stopcock is attached to a pipe by which the feed-pump obtains its supply of water to force into the boiler, and so, by impeding or facilitating the passage of water into the boiler, the attendant may regulate the supply. We have said that this cock is attached to the pipe by which the pump obtains its supply of water, and not to the pipe by which the same pump forces its contents into the boiler it is about to supply; and we have done so for this reason, that it is dangerous to apply such a stopcock on the pipe between the pump and the boiler, because, if the force-pump become once filled with water, and be forced down by the engine when the stopcock is wholly or nearly closed, the pipe will be burst from the incompressibility of the water, unless its valves should be so leaky as to allow the water to pass back into the reservoir from which it has been withdrawn. As, however, it is sometimes desirable to have the regulating cock on the boiler feed-pipe, the following provision is made to render that method of regulation safe and efficient. Between the feed-pump and the boiler, fig. 234, there is inserted, in connexion with the feed-pipe F, at any point V beyond the valve of the pump V^2 which prevents the return of the water into the pump, a loaded escape-valve V; its load W being so adjusted, that whenever the regu-

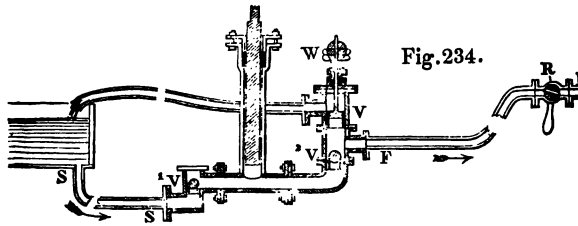
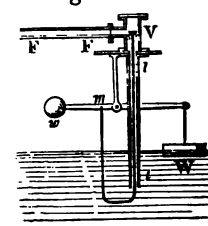


Fig. 234.

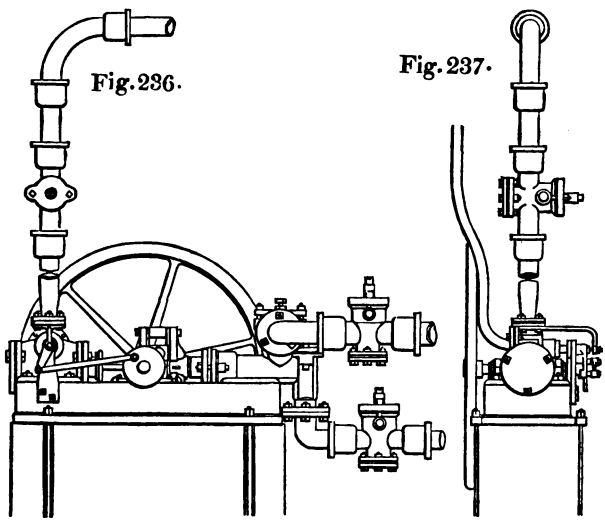
lating stopcock R is turned so as to impede the passage of water towards the boiler B, the force of the feed-pump pushes the water up against the loaded valve V, and by it escapes through the return pipe *r r r* into the reservoir of supply H, again to be brought back into the pump when required for the future supply of the boiler.

Still, however, this apparatus depends in some measure on the adjustment of the regulator-valve R by an attendant; and contrivances have been invented to render this also automatic. In the boiler, and on the surface of the water, is placed a weight W, with a partial counterpoise *w*, so as to rest on the surface of the water. From the point *m* a small rod passe downwards and up again, through the feed-pipe L *l* to the point V, where a conical valve or plug V opens the communication with the feed-pipe F F and the water of the boiler when it is raised, and shuts it again when depressed. Now, when the water is abundant, the weight W floats high, and keeps down *m* and V; and when low, W descends, and raising *m* and V, admits the required supply into the boiler without any assistance.

Fig. 235.



Where a high-pressure boiler is used for purposes in which a steam-engine is not employed, detached self-acting feeding apparatus must be employed. The following elegant and most effective apparatus has been invented by Mr Macdowall of Johnstown, and is now in extensive use in Scotland. We have seen it in an efficient working state, after being employed for many years, and it only costs about £20. It is nothing less than a small steam-engine, but it is applied in a most effective and simple way to the purpose designed.



A very simple feeding apparatus, on a similar principle was adapted some years ago to the purpose of feeding a boiler without the assistance of a steam-engine. A close vessel or reservoir is placed above the level of the boiler, and is in communication with the water

boiler through one pipe, and with the water to be supplied to the boiler through another; a third small pipe connects the steam-chest of the boiler with the top of the said reservoir. All these pipes being closed by moveable regulators or stopcocks, the attendant is first to open the steam communication, that the reservoir may be emptied of air and filled with steam, and the stopcock is then shut. In the next place, the communication with the cold water to be supplied is opened, and the reservoir on getting cool becomes vacuous, so that the pressure of the atmosphere fills it with cold water, and the communication is then cut off. Lastly, the third stopcock is opened, and the water in the reservoir having free communication with the water in the boiler, it is only necessary to open the steam-cock once more, and the water, being in equilibrium by the pressure of the steam, will run freely, by its own pressure, from its height above the boiler, into it; and the process of alternately filling and emptying the boiler may be repeated as often as required by turning the cocks in this succession. A simple process renders all these valves self-acting.

Fig. 238.

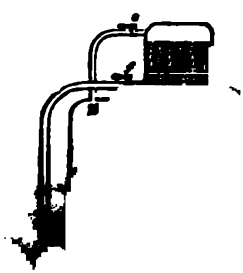
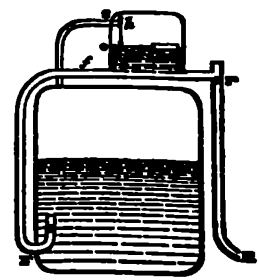


Fig. 239.



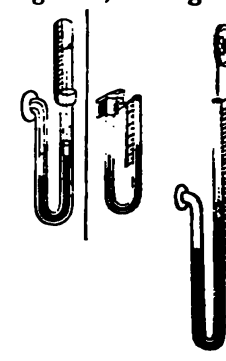
The reservoir, fig. 238, is a close vessel above the boiler B; R *r* is the cold-water pipe, by which the water is obtained, and is regulated by the stopcock *r*; F *f* is the feed-pipe for the boiler, regulated by the stopcock *f*; S *s* is the steam-pipe opened by the stopcock *s*. In the next figure, there is a balanced float on a pivot *o*, and a slit bar *h* connecting a small slide-valve *s* with a pin on the float bar; *r* is a common ball valve, acting only upwards; and in F is a valve permitting the descent of the water in the pipe F *f*, and preventing its return. The latter is of the self-acting form, of which the action once begun will continue indefinitely. A commanding valve being connected with the boiler-float, would render the play of this apparatus dependent on the requirements of the boiler itself. The reader who is acquainted with the steam-engine of Savary, will perceive at once that this reservoir, with its apparatus, is a mere Savary's steam-engine, applied to pump water into the steam boiler; and that this application of that engine is not liable to the objection urged against it in other circumstances, namely, that the water is heated as well as raised. In this instance, the communication of heat is attended with no loss.

Indices of pressure and safety apparatus, form an important series of appendages to a boiler. These are of four kinds; dynamometers, safety-valves, fusible plugs, and alarms.

The dynamometer, which is generally applied to measure the force of steam in a boiler, is a simple tube, bent upwards at the end, and formed sometimes of glass and often of iron. The two ends of this tube being curved up, so as to give it the form of the letter U, one of these

extremities is applied to the boiler, and placed in communication with the steam; mercury is poured into the tube, so as to fill one-half of it, and the pressure of the steam upon one of the extremities of the column of mercury, force the mercury to ascend in the other, and to indicate, on a divided scale, the amount of pressure, which is about one pound on the inch for each inch of height on the scale. It is necessary, in all these mercurial gauges, that the tube be of equal diameter throughout its length. If the tube be of iron instead of glass, it is necessary that a float of wood, or iron, or ivory, figure 240, resting on the top of it, should ascend above the tube, and indicate on a scale the place of the mercury. For high-pressure boilers a longer tube and scale are, of course, necessary; and a very convenient form for this purpose is given in figure 242. From a float resting on the fluid stretches a string carrying a counterpoise at the other end, and passing over a pulley raises or depresses the index of a valve on which the pounds of pressure are indicated by the inches of the scale.

Figs. 240, 241. Fig. 242.



Another very convenient index of pressure, preferable to any other with which we are acquainted, is the piston-gauge. A tube of small diameter, two or three inches, is bored truly cylindrical, and attached to the steam chest of the boiler, figure 243. This cylinder has a solid plug or piston truly turned, and ground exactly, but not loosely, into it. The pressure of the steam bearing up

Fig. 243.

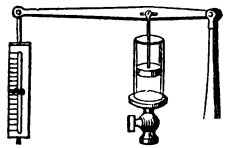


Fig. 244.

the piston on the lever, one end of which is attached to the spring indicator, gives the true indication of the pressure on the piston. The spring is also applied directly above the piston, as shown in the second figure; but this instrument is used on a smaller scale than the other. The ordinary safety-valves are described in another part of this treatise.

There is a species of safety boiler apparatus in which great faith has been placed by many mechanicians and men of science. It has been proposed and enacted that boilers be furnished with fusible plugs, or that, in parts of a boiler exposed to high temperature and pressure, there should be placed plugs, forming small parts of the boiler, which plugs being composed of metals easily melted, shall give way when by accident too great pressure and heat have been employed, and so, by a less evil, prevent the greater one of total disruption of the boiler. This method of creating a less evil to avoid a greater, has lately been shown to be fallacious, and ought to be abandoned. For the complete exposure of the inadequacy of the system of *rodelles fusibles*, we are indebted to the Committee of the Franklin Institute, already so often named with

gratitude. The American experimenters found, that when alloys of tin, lead, and bismuth are applied to steam boilers in the way recommended by the Commission des Rodelles Fusibles, the alloy does not melt in the manner of an homogeneous metal, as has been supposed; but that, in fact, the more fusible metal melts in the minute cells of the less fusible metal, long before the whole mass becomes liquid; that the minutely divided, but more obdurate metal, forms a grating, or rather sponge, in which the other lies melted, so that when the temperature of the steam rises to melt the first metal, the pressure of the steam gradually expels the one metal out of the meshes of the other unmelted metal in globules, in such a manner, that the plate at last consists merely of the one unmelted metal, the other having, by repeated heatings, completely exuded from it, and been replaced by such particles of debris as the water of a boiler in common use always supplies in abundance. Thus, a plate of two metals, originally designed to give way at 250°, may still deceive the unconscious attendant, and withhold its warning till it have reached a temperature of 500°, and contain a combination of caloric and water as dangerous as gunpowder, and greatly more treacherous.

The following experiment will illustrate the whole of this enquiry. A plate of alloyed metals, of which the melting point in the crucible was about 260°, was submitted to heat under pressure. Such a plate would be applied to a boiler, of which the temperature was not designed ever to exceed in the most extreme case one atmosphere, and of which the usual working pressure would not be more than 5 or 10 lbs. It was found that

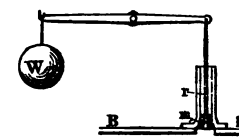
at 256° small particles of melted metal began to exude from the cells of the unmelted metal; the globules thus driven out were carefully examined, and found to be fusible at 222°. At 260°, a second portion exuded, and their dross were found to melt by themselves at 232°. At 270°, the remaining metal was still tenacious, and was not burst until the steam reached a temperature of nearly 300°, with an explosive force of three times that at which it should have given warning by fusion, and the escape of water and steam, from the small aperture it had filled. This last residual porous plate of metal was found not to melt until it reached the temperature of 345° instead of 260°. "These experiments the Committee (properly enough) deem conclusive, in regard to the use of fusible plates in the ordinary way; and they conceive that substituting fusible plugs of greater thickness, say half an inch, as has been directed by a recent ordinance in France, would not serve as a remedy to the defect thus exposed."

The true remedy for this evil was the next object of the enquiries of this excellent Committee. They properly inferred, that the fusion of an alloy of metals at a given temperature was only to be depended on when it was not exposed to the mechanical action of steam, that is, when not exposed to its pressure, but only to its temperature. "The true remedy is to be sought in enclosing the fusible metal in a case, in which it shall not be exposed to the pressure of the steam; so that the more fluid parts of the metal shall not be exposed to being forced out of the mass, but the whole become fluid, as if exposed to heat in a crucible." With this view of the subject, trial was made of an apparatus described by Pro-

fessor Bache, in the Journal of the Franklin Institute for October 1832, under the title of "An Alarm to be applied to Steam Boilers."

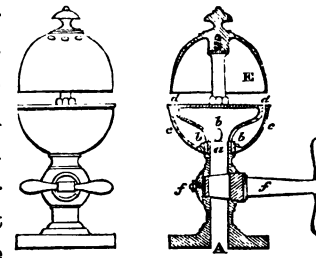
The construction of Professor Bache's alarm is sufficiently simple. "A tube of iron or copper, according to the material of the boiler, closed at the lower end, passes through the top of the boiler, its closed end reaching the flue to which it is attached. This tube, it will be observed, affords a ready access to the flue to ascertain its temperature, without any restraint from packing. A mass of fusible metal placed at the bottom of the tube will become fluid very nearly as soon as the flue takes the temperature of its fusion. To show when the metal at the bottom of the tube becomes fluid, a stone is attached with a cord and weight, or with a lever and weight. The weight and longer arm of the line, descending, may be made to ring a bell, or turn a cock, or open a valve, permitting just enough of steam to issue, to give the alarm. A projection on the lower end of the rod prevents it from being drawn from the metal until this latter is fused,

Fig. 245.



and by widening the lower part of the tube the metal is kept from being drawn out by the rod. BB, fig. 245, is part of the boiler plate; *m* the fusible metal in a tube; *r* the rod to which it is, as it were, soldered, and when the metal melts, the weight W will descend and give the alarm, either by striking a bell, opening a steam whistle or trumpet, or raising a valve. This apparatus of Professor Bache's is a valuable addition to the mechanism of steam.

Fig. 246. Fig. 247.



The common alarms, the steam whistle, and the steam trumpet, may be made to give noisy indications of an excessive pressure of steam. A small box on the steam chest is to cover a lock-up safety-valve, loaded at the highest pressure the boiler should endure. On this box is to be placed a steam whistle or a steam trumpet, so that an alarming noise will be the consequence of any excessive pressure; for the steam issuing through the aperture of the instrument will give it voice with an intensity proportioned to the pressure.

In figs. 246, 247, a steam whistle is represented. A *a* is a tube leading from the boiler; in it is a stopcock. On the top of the tube is a hollow piece *bb*, surrounded by a thin cup *cc*, and carrying, by a pillar fixed on its top, another inverted cup E. When the stopcock is opened, the steam enters the cup *cc* through holes in the foot of the hollow piece *bb*, and rushing out at the narrow orifice *dd*, between the cup *c* and the hollow piece, strikes on the edge of the cup E, and produces an exceedingly loud and shrill sound. No stopcock is, of course, required when this alarm is placed on the box of a safety-valve, in the manner stated above.

On the Proportions of Boilers.—That a boiler when constructed shall be capable of generating a sufficient quantity of steam, without burning an excessive quantity of fuel, without incurring an excessive expense in con-

struction, and without endangering the durability of the metal, subject to the intense heat of the fire, is a problem of engineering of some difficulty, especially when it is attempted to obtain a maximum of effect at a minimum of means, whether the minimum desired be that of weight, bulk, or expense. There are some simple rules deducible from the best practical results that have come under our examination.

The quantity of water to be evaporated in a common steam-engine, is generally reckoned at one cubic foot an hour for each horse power. But if allowance be made for accidental leakage of the boiler, for blowing off at the safety-valves, for priming, and other accidents, an addition of one-fifth part may be provided for. The standard for calculating is, however, one cubic foot of water for each horse power.

The area of the grating in the furnace on which the fuel is laid, is an important element of efficiency in a steam-engine boiler. Here practice somewhat varies. The bars are generally about one inch wide on the top, and the interstice from $\frac{1}{4}$ to $\frac{1}{2}$ an inch. These apertures supply oxygen to the fuel, and regulate the combustion, which is only perfect when the supply of air to the incandescent fuel is ample. It is found that a supply of air, such as will pass through each square foot of the area of the grate of the fire, is adequate to the effectual combustion of so much fuel as will, in a proper boiler, evaporate one cubic foot of water an hour, and supply one horse power in a steam-engine. Thus a fire grate 6 feet long by 6 feet wide, containing $6 \times 6 = 36$ square feet, is found to give an ample supply of air for the combustion of as much fuel as will

supply an engine of 36 horse power, evaporating 36 cubic feet of water an hour. But although this is a safe and excellent proportion for ordinary practice, yet it has been found, that with a quick draught a smaller amount of fire surface is adequate to the effect required. So low a proportion of fire grate as $\frac{2}{3}$ds of a foot, and even $\frac{1}{2}$ of a square foot to each horse power, has been employed by eminent engineers, and has succeeded, while others recommend a much larger allowance even than one square foot. It is certain that the larger area of fire-grate is conducive to economy and durability. The standard of surface is, therefore, to be taken at the most desirable proportion, and only to be deviated from where limited space, as in locomotive-engine and steam-ship boilers, renders this rule inapplicable. This standard is one square foot of area of grate for each horse power.

The next condition on which the success of the boiler problem depends, is the extent of the surface of the boiler acted on by the fire, so as to apply its heat to the water. This is also a subject on which practice varies widely; so widely indeed as from 8 square feet to 36 square feet per horse power. Eight square feet require a clean thin copper boiler, and a very direct impact of the hottest part of the flame, with the loss of a portion of the heat; but 36 square feet, on the contrary, imply the possession of profuse space, and a desire to economise to the very utmost the powers of the fuel. The standard of practical effect with the usual iron boilers, in ordinary circumstances, is fifteen square feet of heating surface for each horse power.

Of this surface, about one-third is horizontal, and two thirds are vertical surface; and of these, the horizontal

surface is imagined to be twice as effective as the vertical surface. Arguing on this supposition, some have given it as a rule to calculate *each vertical foot as only half an effective foot* of heating surface, and so to make nine or ten square feet of effective heating surface the standard of boiler power. But this rule, though giving the same result as the former, proceeds on a supposition not yet established, and which does not always coincide with the fact. It will be easily seen that 5 feet of horizontal surface, added to 10 feet of vertical surface, making, according to the one mode of calculation, 15 feet of surface, divided in the proportion of two-thirds vertical and one-third horizontal surface, forms an exact equivalent to the other mode—of reckoning the 10 feet of vertical surface only equal to 5 effective feet of surface, and adding to the said 5 effective feet of surface the 5 feet of horizontal surface, making in all 10 feet called effective feet of heating surface.

The next essential consideration is the area of the chimney and flues. It has already been given as a standard, that the fire grate should have the area of one square foot for each horse power. Now, this area for the admission of air should be accompanied with a sufficient passage to carry off the gaseous products, and hot air and flame resulting from combustion. From an examination of the best boilers, it appears to us decided that one-fifth of the area of the fire grate, gradually diminishing to a chimney, which shall have one-tenth of the area of the fire grate, is an excellent proportion. We therefore feel disposed to recommend it as a standard for steam-engine boilers: one-fifth, diminished at the chimney to one-tenth part of the area of fire grate.

The chimney should be of the same diameter throughout its interior; and if of 40 feet height and one-tenth part of the area of the fire grate, it will give an abundant draught. If the height of the chimney be greater than this, the area may be diminished as the square root of the height is increased.

The quantity of water to be contained in a boiler is a matter of some importance. If we consider bulk and weight as of no consequence, and if the boiler be in constant work, there cannot, perhaps, be too much water. On the contrary, if there be only a small quantity, many evils are encountered. In the first place, a large mass of water serves to regulate the production of steam from a boiler, much in the same way as a fly-wheel regulates the speed of an engine; whereas with a small charge of water, the unavoidable oscillations that happen in the supply of cold water or the additions to the fire, make sudden and injurious changes in the production of steam. In the next place, it is well known that steam is a very bad conductor of heat, and has a single capacity in its gaseous state for the acquisition of caloric. Hence it is found that if the production of steam be rapid, and the water present in a smaller proportion, the caloric is not carried off from the metal heated by the fire sufficiently fast, the boiler is overheated and rapidly deteriorates, while the production of steam is greatly retarded. For these reasons, it is necessary to have a large supply of water. Eight to thirteen cubic feet are very commonly allowed by practical men. As a standard, or perhaps as a minimum, we may assign for the quantity of water in the boiler, in its mean condition, ten cubic feet of water

in the boiler for each horse power. In like manner we will do well not to leave a smaller proportion of capacity in a boiler for containing steam than the quantity assigned for the water, being ten cubic feet of steam in the boiler for each horse power.

Economy of Fuel in Steam Boilers.—The ordinary consumption of coal by one of Mr Watt's engines is 10 lbs. of fuel for each horse power every hour. The work done by this fuel is equivalent to the power of raising 150 lbs. 220 feet high in a minute, or of raising 220 times 150, that is (220 × 150 = 33,00.) 33,000 lbs. one foot high, or any equal product of mass by height in every minute, by the combustion of 10 lbs. of coal; or 3,300 lbs. of weight raised one foot high every minute, which gives in every hour 198,000 lbs., raised one foot high, by the combustion of one lb. of coal. This, however, by care and economy, is often exceeded by Mr Watt's engines; and the following are about the standards of work done at a given expenditure of fuel in ordinary engines, which is called the Duty of Steam-Engines.

The Duty performed by Ordinary Steam-Engines is—

One horse power exerted by 10 lbs. of fuel an hour.

Quarter of a million of lbs. raised one foot high by one lb. of coal.

Twenty millions of lbs. raised one foot by each bushel of coals.

The constant aim of engineers is to increase the amount of this duty; in other words, to make a less quantity of fuel than 10 lbs. do the work of one horse, or to obtain a greater duty than a quarter of a million

of lbs. from one lb. of fuel, or more than 20 millions of duty from a bushel, or 84 lbs. of fuel. To such an extent has this effort been successful, that one cubic foot of water has been converted into steam capable of exerting one horse power by the combustion of less than 5 lbs. of coal; and this steam has been so managed in the engine as to raise one million of lbs. one foot high by one lb. of coal, and in one case 125 millions of lbs. by a bushel of coals was the duty obtained in Cornwall. Of these improvements part is due to the economy of steam in the engine itself, and does not come under this head. That part, however, which is the result of economy in the boilers, deserves our attention here.

By a series of experiments, carefully conducted or collected, and ably discussed, by Mr Parkes of Warwick, the statistics of steam-engine boilers have been placed in an aspect sufficiently clear to enable us to deduce some general results of considerable economic importance. These experiments are contained in the table at the end of the volume.

The observations contained in this table are made upon three great classes of boilers; the Cornish high-pressure boiler, I. to IV.; the waggon boiler and common low-pressure boiler, V. to XIV.; and the locomotive-engine boiler, XV. and XVI. The waggon boiler, V., was treated at Warwick in a peculiar manner by Mr Parkes himself, who is the advocate of a peculiar system of management, by which very slow combustion of the fuel is produced.

The Cornish boilers, I. to IV., are distinguished from

the common boilers, both in construction and treatment. The surface which they expose to the fire is enormous, being four or five times as great as the standard of usual practice, as we find in I., where 34 horse power has a surface of 2600 feet, and in II., where 48 horse power has a surface of 3170 feet exposed to the fire. This species of boiler is invariably cylindrical, and traversed longitudinally by cylindrical iron flues. It is also surrounded by external flues, except on the upper surface, which is placed under a roof, and enclosed to a considerable depth in sawdust, or other non-conducting matter. The circuit which the flame and hot gases perform, in contact with the flues, is about 150 feet long. The treatment of the Cornish boiler is as peculiar as its structure; for, instead of a strong draught, a tall chimney, and an intense fire, the fuel is laid on in large masses; it is allowed to cake and to consume very slowly, while its products pass up the chimney, after having paid a leisurely visit to the two or three thousand feet of absorbent heating surface that surround its long and circuitous passage towards the open air. Very perfect combustion is obtained by the thorough combination of the oxygen, and the ample time permitted for the communication of the heat thus developed. Durability in the materials used, economy in the fuel employed, and increase of useful effect, are obtained by the Cornish construction and usage, to an extent that excels every other mode of generating steam with which we are acquainted.

The economy of the Cornish boiler and its causes may be estimated by comparison with the standards we have already given of very ordinary practice.

CONDITIONS.	ORDINARY STANDARD.	CORNISH BOILER.
Area of fire grate in square feet	1	2
Area of heating surface in do.....	15	60 to 70
Circuit of heat	60 ft.	150 ft.
RESULTS.		
Fuel per horse power per hour	10 lbs.	$5\frac{1}{4}$ lbs.
Fuel consumed per hour per ft. of grate	10 lbs.	$2\frac{5}{8}$ lbs.
Water evaporated by each lb. of coal.	6 lbs.	$11\frac{1}{3}$ lbs.

The few selections from the valuable magazine of practical facts presented in this table, serve to show how much is to be gained, even without the assistance of new inventions, by judicious construction and treatment of ascertained and practical kinds of boilers and ordinary fuel. A saving of 50 per cent over ordinary practice is gained in Cornwall by large fire grates, thick fires, slow combustion, internal flues, extensive fire surface, and external coverings. He who desires to improve the construction or management of his boilers, has only to fulfil the conditions that are now brought under his attention.

The common waggon boiler stands contrasted in all points with the Cornish boiler. Yet it is cheering to see how much advantage may be gained by judicious construction of fire grate, and a proper system in managing the fire, as is shown in Mr Parkes's experiments on his boiler at Warwick. The only peculiarities of the Warwick treatment appear to have been a large fire grate, $1\frac{3}{4}$ square feet to the horse power, and slow combustion; the high result of 10 lbs. of water evaporated by each pound of fuel, and the economical result of only

6 lbs. of fuel to each H.P. per hour, appear as the reward of this treatment.

The locomotive-engine boiler is in every point contrasted with the Cornish boiler. To pursue this part of the investigation more minutely than its exhibition in the table, would not coincide with the objects of this section.

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THE END.

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		quare foot of grate per hour.	Pounds of water evaporated per square foot of heated surface per hour.	Pounds evaporated by 1lb. of fuel.	Pounds of fuel evaporating one cubic foot of water.	Pounds of water evaporated by the products of combustion per square foot of grate per hour.	Pounds of water evaporated per square foot of heated surface per hour.	Square feet of heated surface to one square foot of grate.	Square feet of heated surface per lb. of fuel burnt per hour.	Square feet of heated surface per lb. of water evaporated per hour from its initial temperat.	Square feet of heated surface per lb. of water evaporated per hour from 212°.	Square feet of heated surface per cubic foot of water evaporated per hour from its initial temp.	Square feet of heated surface
			lbs.	lbs.	lbs.	lbs.	lbs.	sq. ft.	sq. ft	sq. ft.	sq. ft.	sq. ft.	sq
I.	Cornwall. Huel Towan	94	0.829	11.89	5.25	33.66	0.932	35.11	12.75	1.205	1.072	74.67	67
II.	United Mines	90	0.977	11.76	5.31	48.13	1.096	43.88	10.72	1.022	0.911	63.94	56
†II.	Mean of exp. I. & II.	42	0.903	11.82	5.28	40.89	1.014	39.99	11.73	1.113	0.991	69.30	6
III.	East Crinnis		..	..	..	..	..	66.66	9.52	..	..	..	
IV.	Binner Downs		..	..	..	..	..	30.00	.48	..	..	..	
V.	Warwick	68	5.684	10.32	6.05	41.28	6.396	6.45	1.61	0.1759	0.1563	10.99	
VI.	Clithero	90	3.625	6.73	9.27	77.69	4.273	18.18	1.57	0.275	0.234	17.25	14
VII.	Ditto.....	75	4.224	9.79	6.38	78.55	4.970	15.80	1.97	0.236	0.201	14.80	12
VIII.	Preston	74	6.984	8.56	7.28	85.44	8.000	10.70	1.07	0.143	0.194	9.00	7
IX.	Ditto.....	82	7.300	9.67	6.46	89.77	8.388	10.70	1.15	0.135	0.119	8.48	7
X.	Ditto	65	9.311	9.60	6.50	114.13	10.663	10.70	0.900	0.107	0.093	6.71	5
XI.	Albion Mills...	83	6.663	9.63	6.48	158.55	7.448	21.28	1.294	0.150	0.134	9.38	8
XII.	London	71	5.891	7.82	8.00	100.14	6.577	15.22	1.189	0.169	0.152	10.60	9
XIII.	Ditto	98	6.254	9.09	6.87	59.75	7.015	8.51	1.379	0.159	0.142	10.00	8
†XIII.	Mean of exp. VI.—XIV.	83	6.289	8.86	7.15	95.50	7.166	13.88	1.315	0.171	0.149	10.77	9
XIV.	Long Benton ..	25	12.250	8.37	7.46	170.36	13.02	13.08	0.642	0.0816	0.0767	5.10	4
XV.	Manchester & Liverpool Railway....	27	10.360	7.21	8.66	573.25	12.04	47.59	0.581	0.096	0.080	6.02	5
XVI.	Killingworth...	10	21.118	5.17	12.07	235.50	24.48	9.61	0.211	0.047	0.040	2.95	2
	1		21	22	23	24	25	26	27	28	29	30	

DESCRIPTION OF THE PLATES.

Plate I. Figs. 1 and 2. These figures exhibit a front and side elevation of one of the simplest forms of the non-condensing steam-engine. Its principal parts are the cylinder A, the piston-rod P *p*, and connecting rod *p* K, acting directly upon the crank K X, and fly-wheel W W. Besides these there are only an eccentric and valve-rod *x x x*, and governor *w w*. Two columns and an entablature support one extremity of the crank axle, and give attachment to minor appendages. The other extremity of the axle rests on the wall of the building. To the columns is attached *g g* a guide for the top of the piston-rod. The feed pump *fff* is worked by an eccentric on the crank shaft.

Figs. 3 and 4. The form of engine here exhibited is of still greater mathematical simplicity than the last, although its mechanical arrangements are probably more intricate. In this engine no member intervenes between the piston-rod and the crank. A cross-head carried by the piston-rod, open in the centre, permits the crank pin, in its circle of rotation, to oscillate freely on alternate sides of the piston; and being itself powerfully confined to motion in the vertical direction only, by the slides on the columns of the framing, the vertical motion of the piston-rod is precluded from the production of any other dynamical effect than the most direct of all possible conversions of rectilineal into rotatory motion. The cross-head is marked H H in the figure, the columns being headed *m m*. The other letters refer to the same parts as in the last figure.

Plate II. Figs. 1. and 2. In these figures the high-

pressure engine is represented in its most improved form for stationary purposes. It is analogous, in the arrangement of its principal parts, to the usual construction of Bolton and Watt's condensing engine. A cast-iron base supporting six columns and an entablature, forms a framing upon which the parts of the engine are distributed, so as to form what is called a portable engine, being entirely independent of the building in which it may happen to be placed. At one extremity of the base is placed the cylinder A A, and at the other the crank-axle X, and fly-wheel W W. The motion is transferred from the piston P *p*, through the great lever L L L, and connecting rod or crank rod L K. The feed pump *f f* is in this instance worked from the point *m* of the parallel motion, in the way generally adopted in condensing engines for working the air-pump, whose place in fact it here occupies. The valve is a short D-slide, worked by eccentric gear, *x x x x*. S is the steam-pipe. The eduction pipes E are seen descending on both sides of the valve casing; they unite in a common chamber beneath the cylinder, whence a pipe conveys the educted steam to the chimney, or to serve some other purpose, as the case may be. The governor acts as in the previous case. This drawing is taken from the form of engine manufactured by Messrs Caird and Company.

Figs. 3 and 4 is a form of the upright condensing engine manufactured by Messrs Carmichael of Dundee, and successfully applied by them to various purposes. It is compact and has been found to work well.

The cylinder A A is placed upon the floor, and on either side of it stands a cast-iron column. These columns are hollow and are used as steam-pipes, S S S S, to convey the steam to the jacket of the cylinder, from which it finds its way into the valve-chest D. On the

top of the columns is a cross-beam sustaining the crank axle, and the columns support guides *m m m m*, on which, by means of wheels *g g*, and a cross-head *g p g*, the piston-rod P *p* is maintained in its vertical position, so that the connecting rod *p* K is directly attached to the crank-pin K. The air-pump G is worked from the crank-shaft by means of a second crank or bend, and an eccentric *x x* works directly the slide valve; *ff* is the feed-pump for the boiler, worked directly from the air-pump cross-head; *w w w w* is the governor, with its appendages; C is the condenser; N the cold well.

Plate III. In fig. 1. of this plate we have given a sectional elevation of a land-engine of twenty-five inch cylinder and five feet stroke. In fig. 2. we have given its horizontal section at the level of the base of the cylinder, and in the remaining figures the details of its different parts. In figs. 1 and 2 AA is the cylinder, P the piston, P*p* the piston rod, B*b* the parallel motion, LLL the great lever. The pillow blocks L*l*, in which the centre of the great lever works, rest on the spring beam UU, whose ends are secured to the walls of the building in the manner shown on the next plate. The centre of the spring beam is sustained by the columns VV and their entablature *u*, which crosses the building and has its ends secured to the walls like those of the spring beams. At the other end of the great lever are the connecting rod LK, the crank KX, and fly-wheel WW. Returning to the cylinder we have, DD the slide-valves and their casing; *dd* the packing ports. The valve-casing terminates below in EE the eduction-pipe leading into the condenser C. G is the air-pump, F the place of the foot-valve, *h* the air-pump piston rod. The condenser and air-pump with their appendages are placed in the cold well N. M is the hot well, into which the contents of

the air-pump are discharged, and from which the hot water pump *m* draws its supply by the pipe *m'*. The pipe *oo* leads from the hot water pump for the supply of the boiler. The cold well is supplied from the cold water pump *n* by the pipe *n n'*. The rods for working the hot and cold water pumps hang from a stud at either side of the lever at *m*. The governor *ww* is supported on a bracket *tt*, which bridges across the main shaft. The influence of the governor is conveyed to the throttle-valve by the levers and connecting rods *wwww*. The valves are worked by the eccentric *xxxx*. *ff* is the eccentric shaft which carries the gab-lever *f'*, on which the eccentric rod acts; it also carries the levers for working the side rods of the valves, the levers which carry the counterbalance weight, and the socket for the starting lever. The small pillars TT, which surround the cylinder, are surmounted by an entablature which serves as a support for a gangway round the cylinder.

Plate IV. The figures in this plate represent in detail the different parts of the engine which we have just described, separated from each other, in order more clearly to exhibit their construction. Figs. A A' *a a'* show the details of the cylinder. In A A' is shown the upper and lower ports of the cylinder at 1 and 2, and the steam port at 3. In A', 4 is the cylinder cover, and 5 the stuffing box. *a* is an horizontal section of the cylinder, and a plan of the cylinder cover.

Figs. DD' *dd'* show the slide-valve casing; D a front view, D' a side view. 1 and 1 are the packing ports, 2 and 2 the packing-port covers, 3 the eduction-pipe, *d* the cover of the slide-valve casing, 4 its stuffing-box, *d'* a section of the casing. Figs. C, G, F, show a side elevation of the condenser, foot-valve, and air-pump; C,' G', F', a section of these; and *c*, *g*, *f*, a plan of them. 1 is the

cover of the foot-valve, 2 and 3 a section and front view of the valve. Fig. L shows a side view of the great lever, L 1 a top view, and L 2 a transverse section through the centre of it. Figs. KK′ show a front view and section of the crank. Figs. XX*x* show a side view, an end view, and a plan, of the crank shaft pillow block. Figs. *l*, *l* 1, *l* 2, show a side view, an end view, and a plan of the pillow block for the main centre of the great lever. Figs. *mm′* show a vertical and horizontal section of the hot water pump, and figs. *nn′* of the cold water pump. Figs. B 1, 2, 3 are the details of the main links of the parallel motion; *b* 4, 5, 6, 7, 8 details of its air-pump links; 9, 10, 11, 12 side and top views of its radius and parallel bars. 13, 14 is the clutch for the top of piston-rod; 15, 16, the gudgeon and clutch for the top of air-pump rod; 17, 18, top and side views of the ring gudgeon to which the parallel rods are attached; P piston-rod, H air-pump piston rod, *h* air-pump rod, *gg* cold water pump rod and piston rod, and *g′g* hot water pump rod and piston rod, *x* the eccentric, W W, 1, 2, 3, 4 details of the fly-wheel, O main centre or gudgeon for the great lever. PP 1 plan and section of the piston, *w w′* 1, 2, 3, 4, 5 details of the governor, *w* the spindle, *w′* the slide, 1 1 the radius arms to which the balls 5 5 are attached, 2 2 the radius arms which cause the balls to act on the sliding collar *w′*, 3 and 4 the stay for confining the motion of the balls. *t* 1 2 is the slide-valve rod and side rods, *t* 3 is the slide-valve cross-head, R R′ a side and front view of the connecting rod.

Plate V. exhibits a sectional elevation of a condensing engine. This description of house-engine is the design of Mr M'Naught of Glasgow, and has been extensively applied by him to cotton, silk, and saw-mills. The principal peculiarity in its structure is the arrange-

ment by which no further masonry is required for its foundation than the building in which it stands, the usual cold well being dispensed with, and the whole structure connected by cast-iron beams with the walls of the house. The cylinder AA is attached immediately to TT, the cast-iron beams of the floor, which are deeply bedded in the wall at T and T, and rests directly upon the large vessel C, which forms the condenser, and is supported likewise by beams YY, which are bedded in the walls. The condensation is effected by injection alone, without the usual accompaniment of a cold well around the condenser, an appendage that may safely be regarded as by no means indispensable to the practical perfection of the vacuum—when the vessel itself is formed with few joints. The transverse beams of the buildings are supported by two pillars directly under the centre of the great lever LLL, so as to support the main centre L; and the crank-axle X and the axis Z of the fly-wheel W, are supported on UU, another beam of cast iron.

The steam enters the house through the pipe SS, passes round the cylinder to SS, around the long slide-valve DD, being confined to the middle of it by the valve packing *hh*, and after performing its duty in the cylinder, passes out at EEE into the condenser C, where it is finally condensed into water. Hence it is drawn off at the foot-valve F by the piston H of the air-pump G, and delivered by the discharge-valve M into N, the hot well. The slide-valve DD is worked by the eccentric gear *xxxx* and the rod *d*D through a moveable stuffing-box *dx*.

Plates VI. and VII. These plates represent the high-pressure engines which are employed to work the inclined plane at the Liverpool station on the Liverpool and Manchester Railway. They are beautiful and in

many respects highly judicious; they are the work of Messrs Mather, Dixon & Co., Liverpool.

WWW, Plate VII. is the great wheel which works the rope that draws the railway train up the inclined plane; the rope is contained in a groove in the edge of the wheel. A clutch *kk* connects or disconnects the crank-axle XXX with the wheel WW; the cranks KX, KX, KX are placed at right angles, so that when one is on the centre the other is at the furthest distance from it. K*k*, the connecting rod, hangs down from LL, the ends of the levers. The centre of the side levers, IV., rests on a truss at no greater height than three feet above the floor of the engine-room. L*p* is a side rod by which the levers are united to the cross-head *rpr*. The steam in this instance comes about a quarter of a mile from the boilers to the cylinders AA by the steam-pipe SSS. Fig. 2 is a section of the steam-valves and cylinder. The valves DD are short D-slides, surrounded by steam, and by the underside of the valves the escape takes place through the space E; *d*D is the valve-rod moved by the usual valve-gear *xxx*. The eccentric *xxx*, Plate VI., is placed on a long shaft from the crank axle at X, which shaft is also employed to work the governor-balls *ww*. The whole foundations are solid red sandstone rock, in which excavations are made for the shafts and ropes.

Plates IX, X, and XI. This very beautiful pair of engines was constructed by Mr Fairbairn of Manchester; and they are the property of Messrs Bailey and Co. of Staley Bridge, near Manchester. They are employed to drive a cotton-mill, and possess many excellent adaptations to this purpose.

These engines are of a similar form to those employed in large steam vessels, and will serve very well to conduct

the student from the common to the marine engine. The working beam or great lever LLL is, as it were, split in two, one of the halves being placed on each side of the engine, but united at the middle by a large gudgeon or main-centre, LL, and at the one end by a cross-head, *Lp*L, and side rods, RL and RL, and at the other end by a cross-tail of similar form, and the connecting rod KL, which turns the crank KX. The moving mass is thus placed lower, and the whole rendered more compact, than the common house engine.

This double marine engine is reckoned preferable in the manufacture of cotton to an engine of the common kind. The double engine gives a considerable degree of uniformity to the velocity produced; and the approximation to uniformity is rendered still more perfect by the short stroke, in which the variations of force recur at shorter intervals than with a long stroke. A striking peculiarity in this pair of engines is the large fly-wheel, WWW, formed of toothed segments, which receives the moving force of both engines, and gives it out directly, and with a high velocity, to the mill shafts, YY. Not only is the requisite speed of revolution attained very readily and quickly by this means, but the momentum of the wheel is immediately conveyed to the shaft, instead of passing through a series of wheel and axle work. The durability and excellence of this arrangement are unquestionable.

The section, plate IX., shows the details of many of the parts. The steam-pipe SSS from the boiler conducts the steam into a space SS, forming a jacket round the cylinder AA. The piston P has metallic rings on its periphery as packing; U and V, the upper and lower steam-ports, are wholly formed in the cover and bottom plate of the cylinder, and are closed and

opened alternately by two short D-slides in two separate valve-chests above and below. The steam enters the upper chest from the jacket at S, where the throttle valve is inserted, and passes through the valve. The packing on the back of the valve is screwed down from above by a vertical spindle, and the eduction takes place through E by a hollow vertical column on one side of the valve-chest, while the steam passes down to the lower port through another column. The condenser C is a single casting, placed immediately below the valve-chest, and is entered by the injection pipe *cc* at *c*, of which the aperture is regulated by a slide-valve and vertical spindle ending in a screw. F is the foot-valve, governing the communication between the condenser and air-pump G; H is the air-pump piston, with common clack valves; and M is the delivery valve, opening outwards into the hot well. The waste pipe is immediately below M; and the feed pump and pipe *f* are in the masonry below the lever, so as to draw the feed water from the waste pipe.

The valves DD receive motion by an apparatus somewhat peculiar. A stud in the crank pin K carries round a small radius rod *x x* on an axis, concentric with the crank; a smaller crank on this axis or shaft has a length equal to half the throw of the valve, or equal to that which would be given to the usual eccentric, and by a bar *x x* similar to the eccentric rod, the valve is moved by this lesser crank, just as by an eccentric. This gearing has the advantage of lightness and precision. *m m m* are the usual links of the parallel motion; *d* is a counterpoise to the weight of the valve, *w w* are the weights of the governor.

Plate XV. This is one of that class called the rotatory steam-engine; a class comprehending many varieties of which we hear much and see but little. The engine

is given as an illustration of this very unsuccessful class of engines, by one of its least exceptionable examples. It has actually been in use for some years, being frequently employed to turn the machinery of a large establishment. We have seen it working smoothly and well; yet we have not been able to recognize in it any reason for giving it an equality, much less a preference, in comparison with the common engine. It can be reversed in the same way as a common engine. It was invented by Mr Yule of Glasgow, by whom it was patented, and is still in the works of the late Thomas Edington, Esq., at Glasgow.

SSS is a double steam pipe, either branch of which may be employed according as the engine is to go forward or backward. AA is the cylinder firmly fixed on a stone foundation, and in its centre is an axis XX, upon one side of which and eccentric to the cylinder is an inner cylinder or barrel turned quite true, and fixed to revolve with the axis X, and so to form the piston P, which is to receive and give out the force of the steam. RR furnishes the *point d'appui*, the surface of reaction, which resists the force of the steam and forms a fixed obstacle. It flat slide or sluice, (see fig. 5,) resting on the barrel piston P, and maintained by guides always in a vertical position. It passes into the cylinder through a rectangular stuffing box, and is raised and depressed by a small eccentric pin *x x*, so as to remain always upon the surface of the piston drum. All the working surfaces are rendered steam-tight by metallic packings. EEE is the eduction passage into the condenser or the open air, DD are slide valves to be reversed when the engine is to go backwards. On the revolving axis of the piston X are toothed wheels, *gg*, working other two, *gg*, which have a common axis *zz*, carrying a fly-wheel, and driv-

ing the machinery to be worked by the engine. Fig 6. shows the ports at DD. Fig. 7 shows the guides of the slide RR.

Plates XII. XIII. XIV. exhibit views of a pair of beautiful marine engines, constructed by Mr Napier, for the four British and North American royal mail steam-ships Britannia, Acadia, Caledonia and Columbia, plying between Liverpool, Halifax, (Nova Scotia) and Boston, (U. S.) The following are the general dimensions of the vessel and engines.

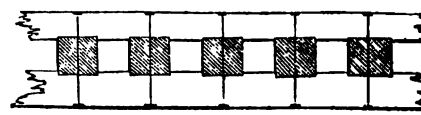
	Ft.	in.
Length from figure-head to taffrail, .	228	
Length of keel and fore-rake, . .	206	
Breadth of beam between paddles, .	34	6
Depth of hold, ...	22	6
Diameter of paddle-wheel, . .	28	
Length of floats, . . .	26	
Diameter of cylinder, . . .	6	
Length of stroke, . . .	6	10

The power of the engines is about 240 horse power. The paddle shafts make 16 revolutions per minute The tonnage of the vessel by the old law is about 1200 tons.

Plate XII is a side elevation of one of the engines.

Plate XIII is the elevation of the crank end of the engines, and Plate IV the elevation of the cylinder end. By an inspection of these engravings it will be seen, that the parts of the engines are sustained by an elegant and rigid Gothic framing, rendering them, notwithstanding the ponderosity of their different parts, entirely independent of the vessel on which they are placed. AA are the cylinders, B the slide-valve casing, C the condenser, D the hot well and air-vessel placed on the top of the condenser. E the air-pump,

FF the feed pumps. The moving parts of the engine are as follow:—K the cylinder piston-rod, I the cross-head, H the cylinder side rods descending to the great side levers GGG. Connected with the parts last described are the radius rods of the parallel motion L, the motion side rod L′, and the parallel motion shaft *l*, V the valve or weigh-shaft on which is fixed the valve lever W, whose other end is inserted into a clutch on the slide-valve link *c*. On either side of the centre of the great lever depends a side rod *ff*, to work the bilge and brine pumps, and to its extremitty are attached the links of the cross-tail of the connecting rods, P the links, Q the cross-tail, R the connecting rod. To the upper end of the connecting rod is attached the crank S; T is the intermediate or crank-shaft, T′T′ the paddle-wheel shafts. On the crank-shaft is placed the eccentric U; and *uu* is the eccentric rod working the eccentric gab-lever *v* on the valve or weigh-shaft *t t*². Y *y y* the expansion valve apparatus, *h h* escape valves at top and bottom of cylinders, X paddle wheels, *k* lever for starting the engines, 1 1 steam-pipes, 2 2 waste water pipes from hot well, 3 double force-pump for filling boilers, extinguishing fires, and washing decks, 4 4 engine beams, 5 5 5 5 midship section of vessel, 6 6 thick planks checked in upon and bolted through the timbers thus:—



FF the feed pumps. The moving parts of the engine are as follow:—K the cylinder piston-rod, I the cross-head, H the cylinder side rods descending to the great side levers GGG. Connected with the parts last described are the radius rods of the parallel motion L, the motion side rod L′, and the parallel motion shaft *l*, V the valve or weigh-shaft on which is fixed the valve lever W, whose other end is inserted into a clutch on the slide-valve link *c*. On either side of the centre of the great lever depends a side rod *ff*, to work the bilge and brine pumps, and to its extremitty are attached the links of the cross-tail of the connecting rods, P the links, Q the cross-tail, R the connecting rod. To the upper end of the connecting rod is attached the crank S; T is the intermediate or crank-shaft, T′T′ the paddle-wheel shafts. On the crank-shaft is placed the eccentric U; and *uu* is the eccentric rod working the eccentric gab-lever *v* on the valve or weigh-shaft $t\ t^2$. Y *y y* the expansion valve apparatus, *h h* escape valves at top and bottom of cylinders, X paddle wheels, *k* lever for starting the engines, 1 1 steam-pipes, 2 2 waste water pipes from hot well, 3 double force-pump for filling boilers, extinguishing fires, and washing decks, 4 4 engine beams, 5 5 5 5 midship section of vessel, 6 6 thick planks checked in upon and bolted through the timbers thus:—

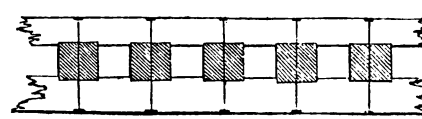
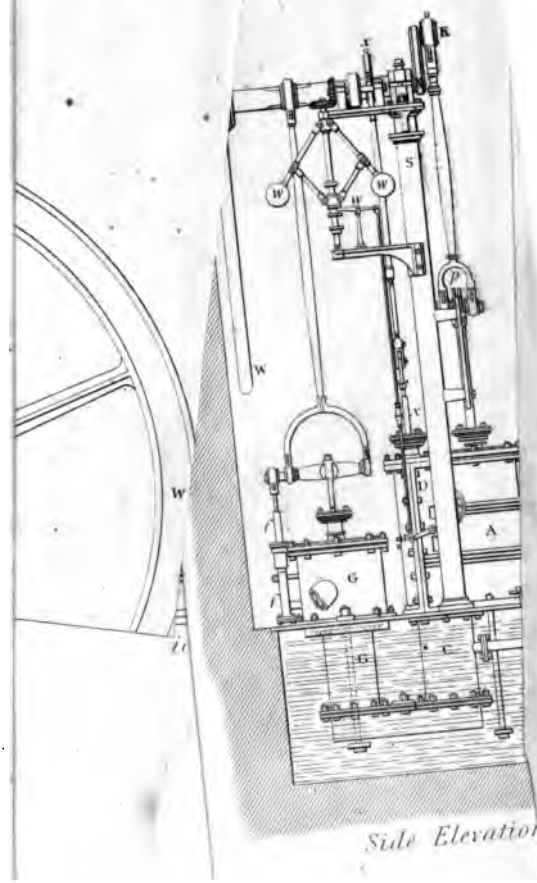


PLATE II.

Fig. 4.



Side Elevation

PLA

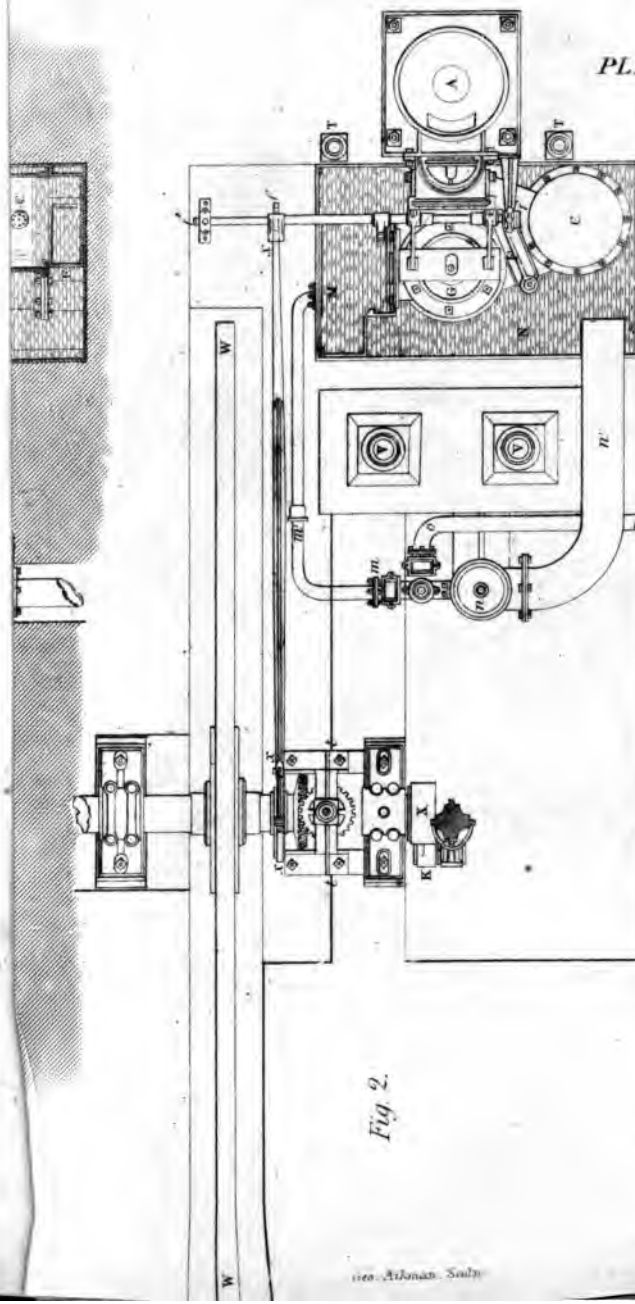
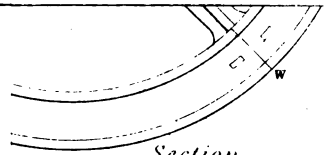
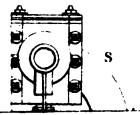


Fig. 2.

Geo. Arkman. Sculp.



Section.



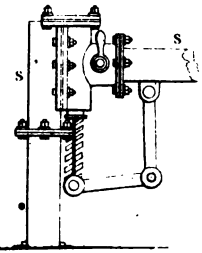
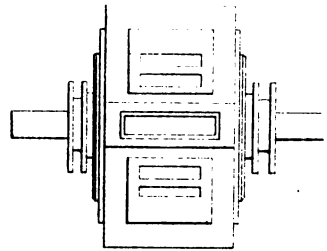


Fig. 4.



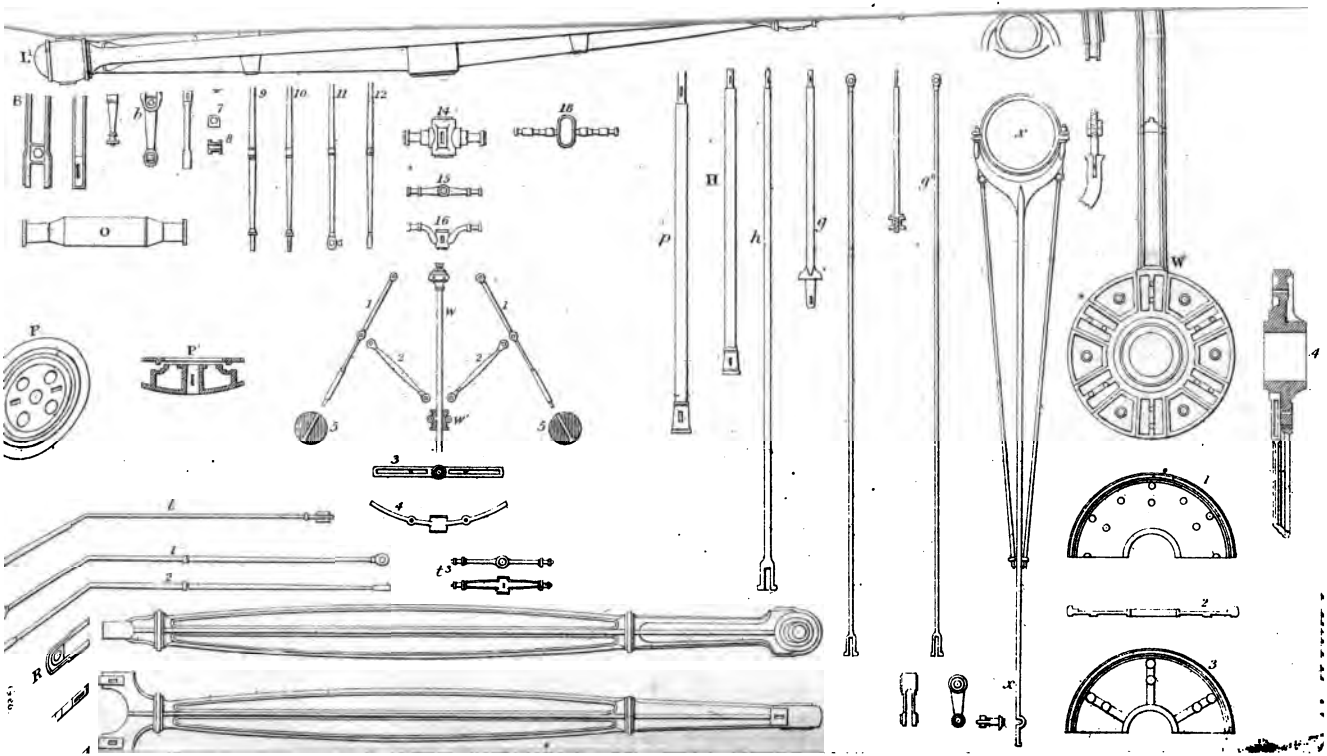


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PLATE V.

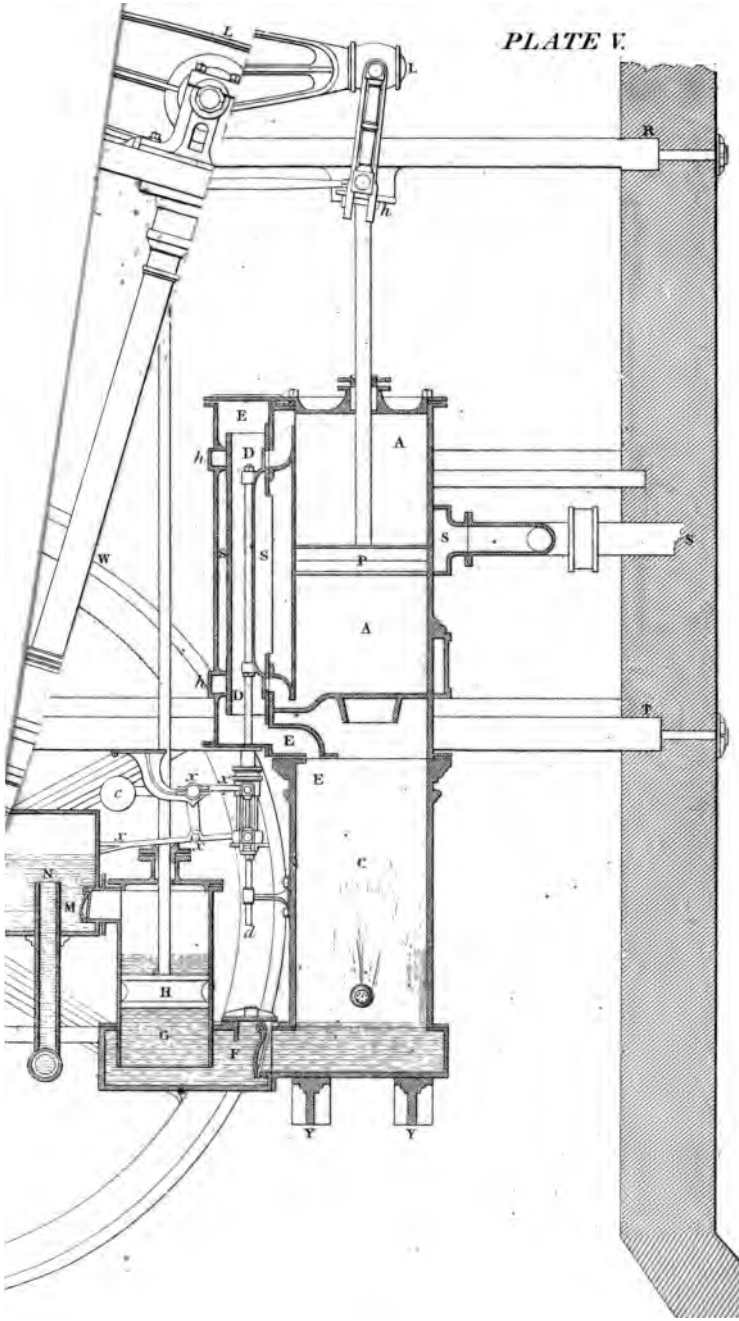


PLATE VII.

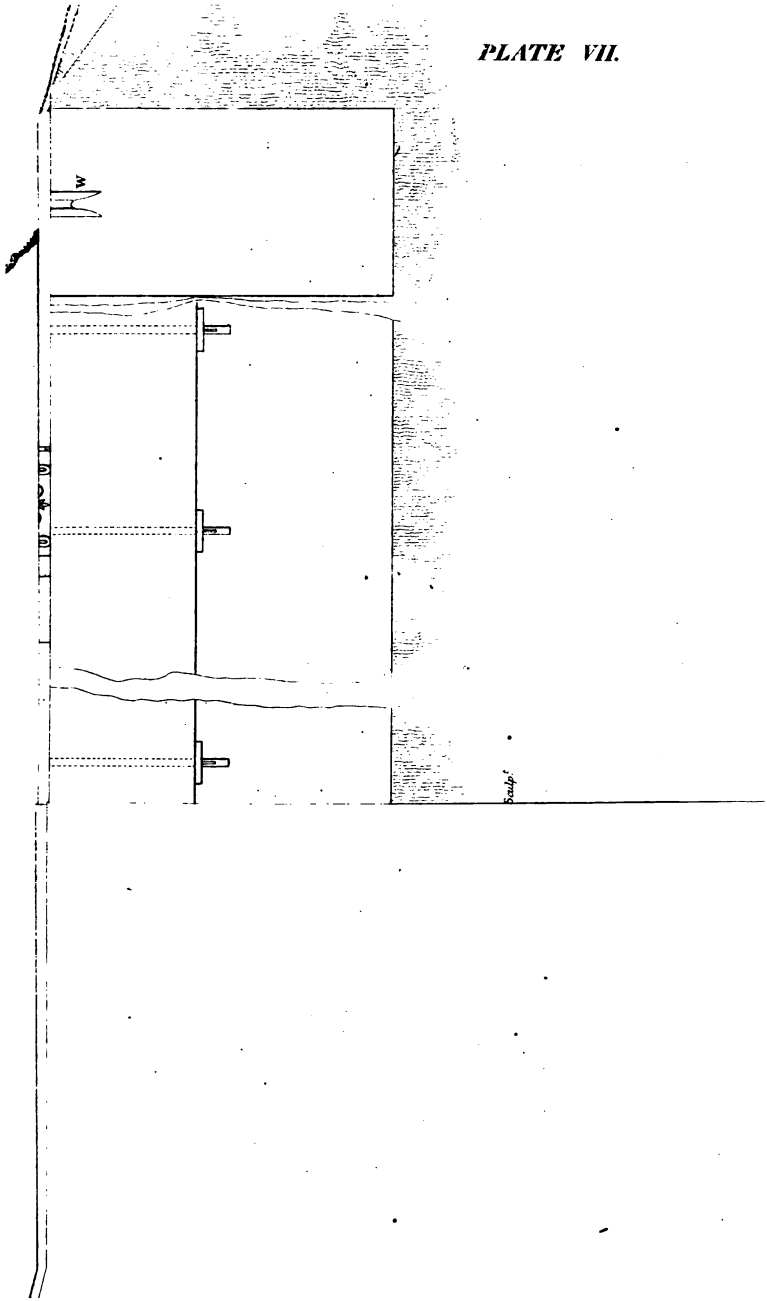
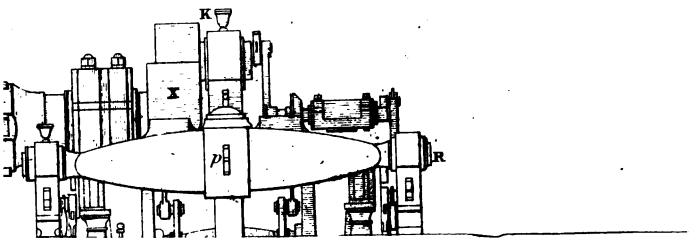


PLATE VIII.

Fig. 2.



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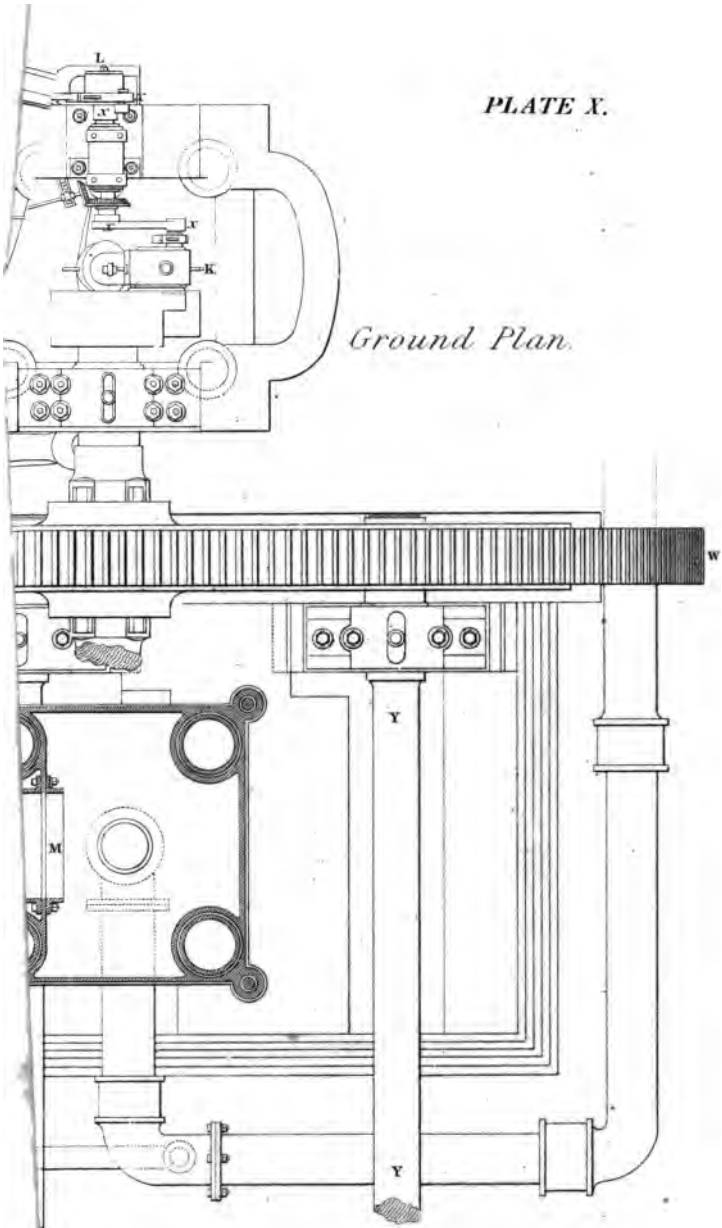
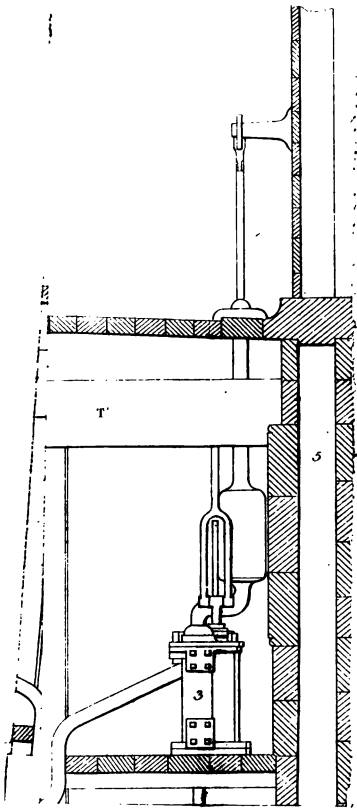


Ground Plan.

271.

Geo. Aikman, Sculpt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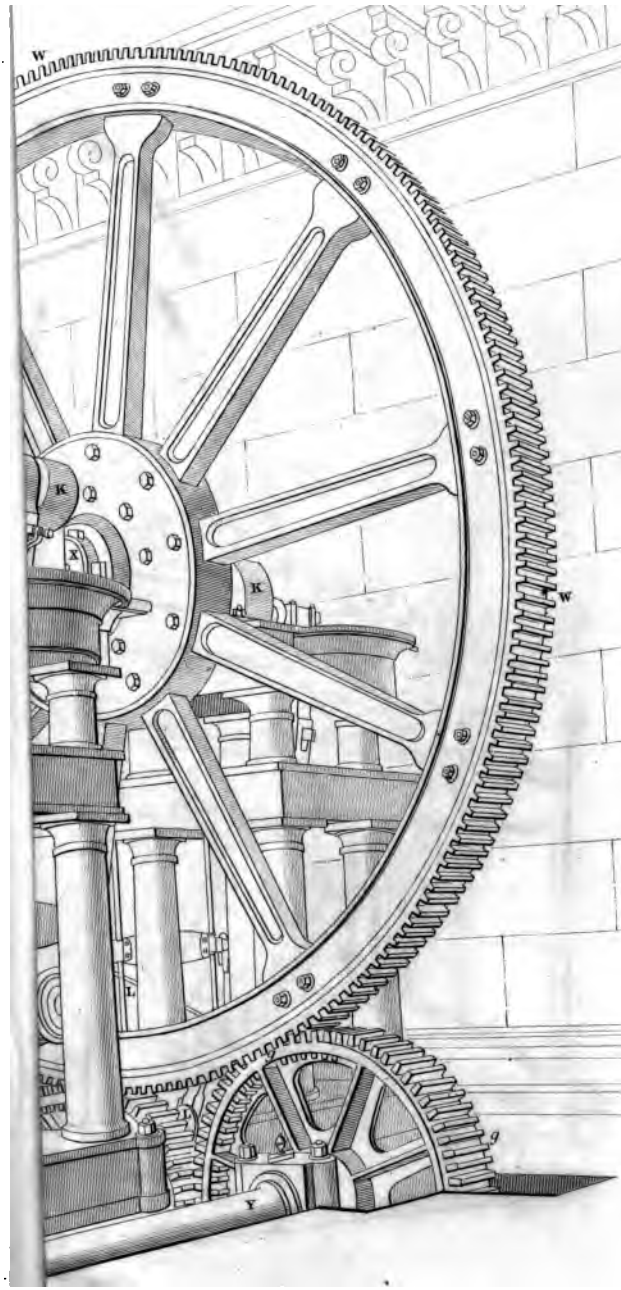
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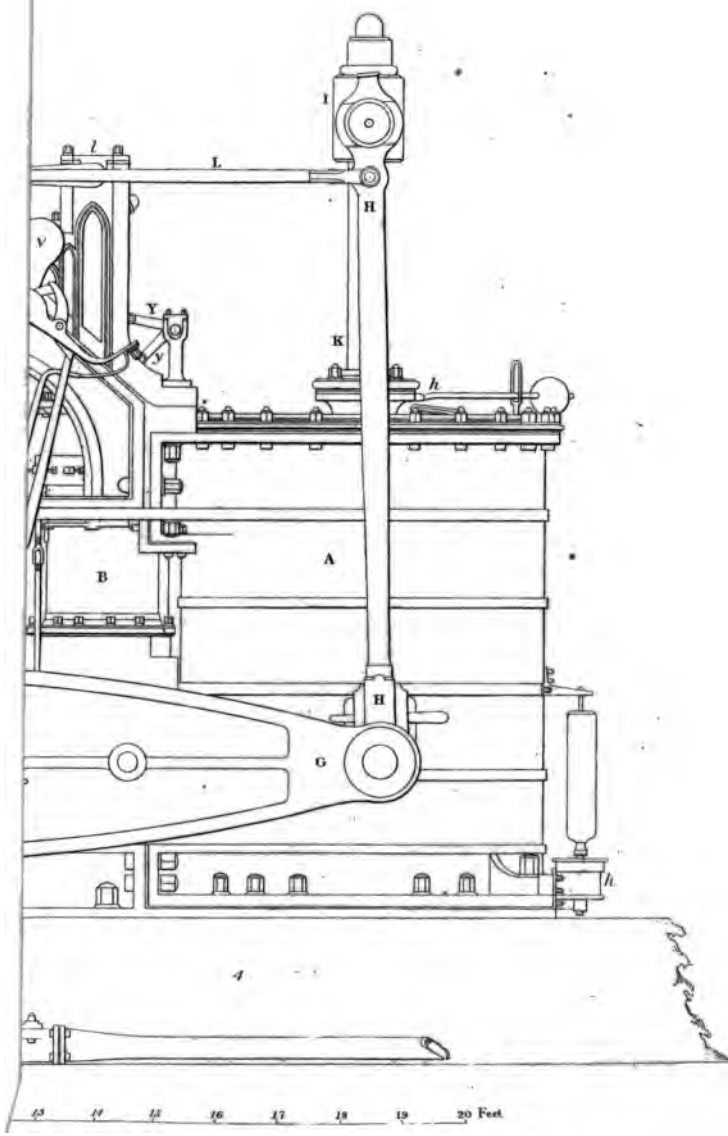
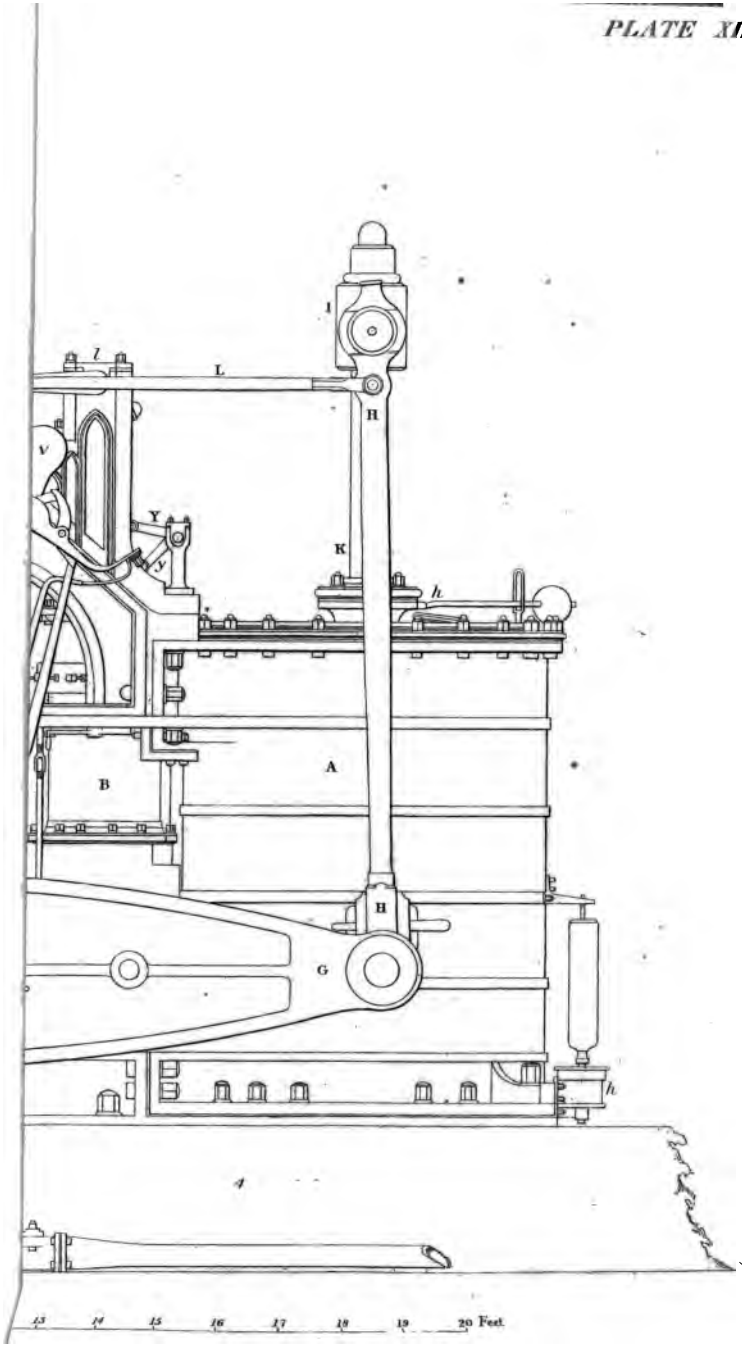
PLATE XII.

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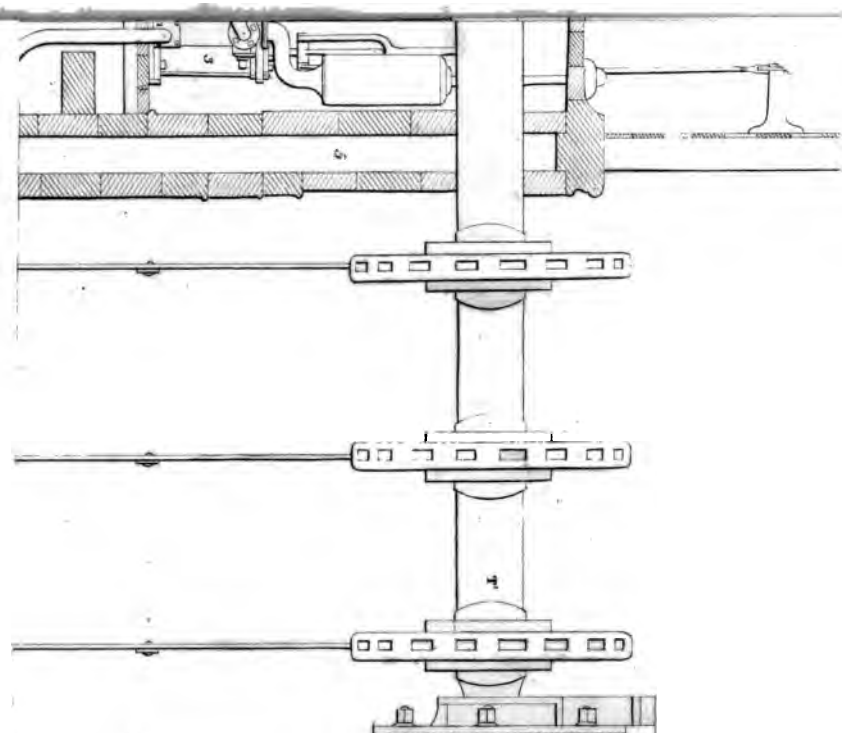

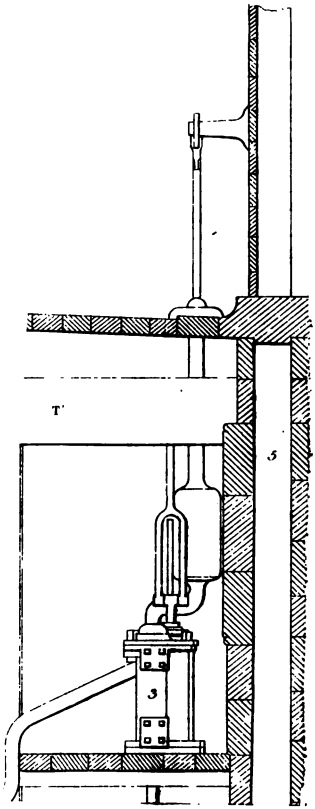
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